HYDROMECHANICS
MINE DRAINAGE

INTERNATIONAL
TEXTBOOK COMPANY
SCRANTON, PA.

Hydromechanics
Mine Drainage

International Correspondence Schools

By
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MINE DRAINAGE

449

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1906

Printed in U. S. A.

INTERNATIONAL TEXTBOOK PRESS
Scranton, Pa.

77954

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NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

HYDROMECHANICS

MINE DRAINAGE

HYDROMECHANICS

Serial 853 Edition 1

HYDROSTATICS

LAWS OF LIQUID PRESSURE

1. **Hydrostatics** treats of the pressure and equilibrium of practically incompressible fluids. A pressure of 15 pounds per square inch compresses water less than $\frac{1}{200000}$ of its volume; water is, therefore, practically incompressible.

2. Fig. 1 represents two cylindrical vessels of the same size. The inside of vessel *a* is fitted with a wooden block up to the piston *P*; the vessel *b* is filled with water to a depth equal to the length of the wooden block in *a*. Both vessels are fitted with air-tight pistons *P*, whose areas are each 10 square inches.

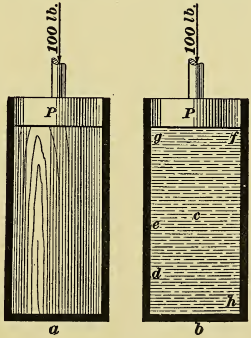


FIG. 1

Suppose, for convenience in calculation, that the weights of the cylinders, pistons, block, and water be neglected, and that a force of 100 pounds be applied to both pistons. The pressure per square inch will be $\frac{100}{10} = 10$ pounds. This pressure will be transmitted to the bottom of the vessel *a* and will be 10 pounds per square inch; there will be no pressure on the sides. In the vessel *b*, the pressure

on the bottom will be the same as in the other case, that is, 10 pounds per square inch, but, owing to the fact that the molecules of the water are perfectly free to move, this pressure is transmitted in every direction with the same intensity; that is to say, the pressure at any point, *c*, *d*, *e*, *f*, *g*, *h*, etc., due to the force of 100 pounds, is exactly the same and equals 10 pounds per square inch.

3. Pascal's Law.—*The pressure per unit of area exerted anywhere on a mass of liquid is transmitted undiminished in all directions and acts with the same intensity on all surfaces in a direction at right angles to those surfaces.*

This may be proved experimentally by means of the apparatus shown in Fig. 2. Let the area of the pistons *a*, *b*, *c*, *d*, *e*, and *f* be 20, 7, 1, 6, 8, and 4 square inches, respectively.

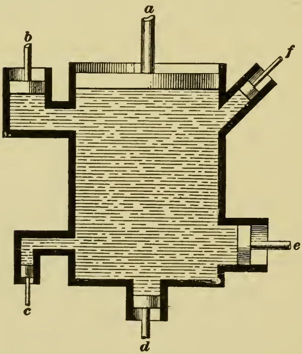


Fig. 2

If the pressure due to the weight of the water be neglected and a force of 5 pounds be applied at *c* (whose area is 1 square inch), a pressure of 5 pounds per square inch will be transmitted in all directions; in order that there shall be no movement, a force of $6 \times 5 = 30$ pounds must be applied at *d*, 40 pounds at *e*, 20 pounds at *f*, 100 pounds at *a*, and 35 pounds at *b*.

If a force of 99 pounds were applied to *a*, instead of 100 pounds, the piston *a* would rise and the other pistons, *b*, *c*, *d*, *e*, and *f*, would move inwards; but if the force applied to *a* were 100 pounds, they would all be in equilibrium. Suppose 101 pounds to be applied at *a*; the pressure per square inch $\frac{101}{20} = 5.05$ pounds would be transmitted in all directions; then, since the pressure due to *c* is only 5 pounds per square inch, it is evident

that the piston *a* would move downwards, and the pistons *b*, *c*, *d*, *e*, and *f* would be forced outwards.

The pressure due to the weight of a liquid may be downwards, upwards, or sidewise.

4. Downward Pressure.—In Fig. 3, the pressure on the bottom of the vessel *a* is equal to the weight of the water it contains. If the areas of the bottoms of vessels *a* and *b* and the depth of the liquids contained in them are the same, the pressures on the bottoms of the vessels will be the same. Suppose that the bottoms of the vessels are 6 inches square, that the part *c d*, in the vessel *b*, is 2 inches square, and that the vessels are filled with water. The weight of 1 cubic inch of water is $\frac{62.5}{1{,}728} = .03617$ pound.

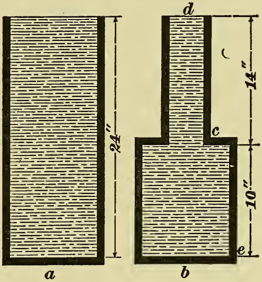


Fig. 3

The number of cubic inches in *a* will be $6 \times 6 \times 24 = 864$. The weight of the water will be $864 \times .03617 = 31.25$ pounds. Hence, the total pressure on the bottom of *a* will be 31.25 pounds, or .868 pound per square inch. The pressure in *b* due to the weight contained in the part *b c* is $6 \times 6 \times 10 \times .03617 = 13.02$ pounds. The weight of the part contained in *c d* is $2 \times 2 \times 14 \times .03617 = 2.0255$ pounds, and the weight per square inch of area in *c d* is $\frac{2.0255}{4} = .5064$ pound.

According to Pascal's law, this weight (pressure) is transmitted equally in all directions; therefore, every square inch of the top of the large part of the vessel *b* will be subjected to a pressure of .5064 pound. The area of the part *b c* is $6 \times 6 = 36$ square inches, and the total pressure due to the weight of the water in the small part will be $.5064 \times 36 = 18.23$ pounds. Hence, the total pressure on the bottom of *b* will be $13.02 + 18.23 = 31.25$ pounds, the same result as in the case of the vessel *a*.

If an additional pressure of 10 pounds per square inch were applied to the upper surface of both vessels, the total pressure on their bottoms would be $31.25 + (6 \times 6 \times 10) = 31.25 + 360 = 391.25$ pounds.

If this pressure were obtained by means of a weight placed on a piston, as shown in Figs. 1 and 2, the weight necessary to cause this pressure for the vessel *a* would be $6 \times 6 \times 10 = 360$ pounds and for the vessel *b*, $2 \times 2 \times 10 = 40$ pounds.

5. Law.—*The pressure on the bottom of a vessel containing a fluid is independent of the shape of the vessel, and is equal to the weight of a prism of the fluid whose base is the same as the bottom of the vessel and whose altitude is the distance between the bottom and the upper surface of the fluid, plus the pressure per unit of area on the upper surface of the fluid multiplied by the area of the bottom of the vessel.*

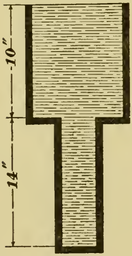


Fig. 4

Suppose that the vessel *b*, Fig. 3, were inverted, as shown in Fig. 4, the pressure on the bottom would still be .868 pound per square inch, but it would require a weight of 3,490 pounds to be placed on a piston at the upper surface to make the pressure on the bottom 391.25 pounds, instead of a weight of 40 pounds, as in the other case.

Example.—A vessel filled with salt water having a specific gravity of 1.03 has a circular bottom 13 inches in diameter; the top of the vessel is fitted with a piston 3 inches in diameter, on which is laid a weight of 75 pounds. What is the total pressure on the bottom if the depth of the water is 18 inches?

Solution.—The weight of 1 cu. in. of the water is $\frac{62.5 \times 1.03}{1{,}728} = .037254$ lb. $13 \times 13 \times .7854 \times 18 \times .037254 = 89.01$ lb., or the pressure due to the weight of the water. $\frac{75}{3 \times 3 \times .7854} = 10.61$ lb. per sq. in. due to the weight on the piston. $13 \times 13 \times .7854 \times 10.61 = 1{,}408.29$ lb. Total pressure is $1{,}408.29 + 89.01 = 1{,}497.3$ lb. Ans.

6. Upward Pressure.—In Fig. 5 is represented a vessel of exactly the same size as that represented in Fig. 4. There is no upward pressure on the surface *c* due to the weight of the water in the large part *c d*, but there is an upward pressure on *c* due to the weight of the water in the small part *b c*. The pressure per square inch due to the weight of the water in *b c* was found to be .5064 pound; the area of the upper surface *c* of the large part *c d* is evidently $(6 \times 6) - (2 \times 2) = 36 - 4 = 32$ square inches, and the total upward pressure due to the weight of the water is $.5064 \times 32 = 16.2$ pounds.

If an additional pressure of 10 pounds per square inch were applied to a piston fitting the top of the vessel, the total upward pressure on the surface *c* would be $16.2 + (32 \times 10) = 336.2$ pounds.

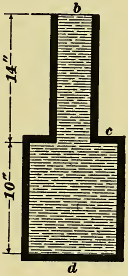


FIG. 5

EXAMPLE.—A horizontal surface 6 inches by 4 inches is submerged in a vessel of water 26 inches below the upper surface; if the pressure on the water is 16 pounds per square inch, what is the total upward pressure on the horizontal surface?

SOLUTION.— $4 \times 6 \times 26 \times .03617 = 22.57$ lb., the upward pressure due to the weight of the water. $6 \times 4 \times 16 = 384$ lb., the upward pressure due to the outside pressure of 16 lb. per sq. in. The total upward pressure is $384 + 22.57 = 406.57$ lb. Ans.

7. Lateral Pressure.—Suppose that the top of the vessel shown in Fig. 6 is 10 inches square and that the projections at *a* and *b* are 1 in. $\times$ 1 in. and 10 inches long.

The pressure per square inch on the bottom of the vessel due to the weight of a liquid will be $1 \times 1 \times 18 \times$ the weight of a cubic inch of the liquid.

The pressure at a depth equal to the distance of the upper surface of *b* will be $1 \times 1 \times 17 \times$ the weight of a cubic inch of the liquid.

Since both these pressures are transmitted in every direction, they are also transmitted sidewise, and the pressure per unit of area on the projection *b* is a mean between the two and equals $1 \times 1 \times 17\frac{1}{2} \times$ the weight of a cubic inch of the liquid.

To find the lateral pressure on the projection *a*, imagine that the dotted line *c* is the bottom of the vessel; then the conditions will be the same as in the preceding case, except that the depth is not so great.

The lateral pressure on *a* is thus seen to be $1 \times 1 \times 11\frac{1}{2}$ $\times$ the weight of a cubic inch of the liquid.

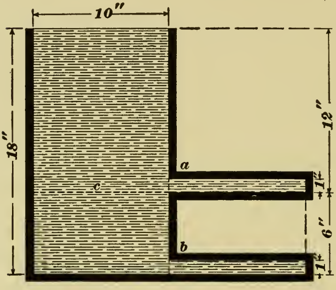


FIG. 6

EXAMPLE.—(*a*) A well 3 feet in diameter and 20 feet deep is filled with water; what is the pressure on a strip of the wall 1 inch wide, the center of which is 1 foot from the bottom? (*b*) What is the pressure on the bottom? (*c*) What is the upward pressure per square inch 2 feet 6 inches from the bottom?

SOLUTION.—(*a*) $1 \times 36 \times 3.1416 = 113.1$ sq. in., the area of the strip. $113.1 \times 19 \times 12 \times .03617 = 932.71$ lb., the total pressure on the strip. Ans.

(*b*) The pressure per square inch will be $\frac{932.71}{113.1} = 8.247$ lb., nearly. Then, $36 \times 36 \times .7854 \times 20 \times 12 \times .03617 =$ 8,836 lb., the pressure on the bottom. Ans.

(*c*) $20 - 2.5 = 17.5$. $1 \times 17.5 \times 12 \times .03617 = 7.596$ lb., the upward pressure per square inch 2 ft. 6 in. from the bottom. Ans.

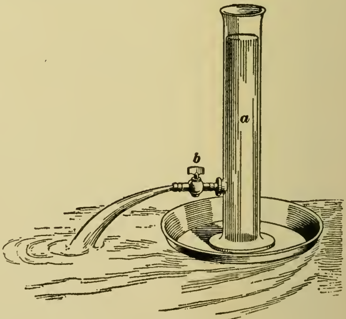


FIG. 7

8. A tall vessel *a* having a stop-cock *b* near its base and arranged to float on the water, as shown in Fig. 7, illustrates the effects of lateral pressure. When this vessel is filled

with water, the lateral pressures, at any two points of the surface of the vessel opposite to each other are equal. Being equal and acting in opposite directions, they balance each other, and no motion can result; but if the stop-cock is opened, there will be no resistance to that pressure acting on the surface equal to the area of the opening, and it will cause the water to flow out, while its equal and opposite force will cause the vessel to move through the water in a direction opposite to that of the spouting water.

9. The laws of liquid pressure given in the preceding articles may be embraced in the following formula:

$$P = a\,(dw + p)$$

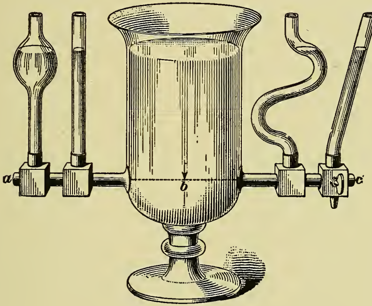


Fig. 8

in which a = area of a submerged surface, in square inches;
d = distance, in inches, of center of gravity of surface from surface of liquid;
w = weight of a cubic inch of the fluid, in pounds;
p = pressure on surface of liquid, in pounds per square inch;
P = total pressure on submerged surface, in pounds.

10. Since the pressure on the bottom of a vessel due to the weight of the liquid is dependent only on the height of the liquid, and not on the shape of the vessel, it follows that

if a vessel has a number of radiating tubes, as shown in Fig. 8, the water in each tube will be on the same level, no matter what may be the shape of the tubes. For, if the water were higher in one tube than in the others, the downward pressure on the bottom due to the height of the water in this tube would be greater than that due to the height of the water in the other tubes. Consequently, the upward pressure would also be greater, the equilibrium would be destroyed, and the water would flow from this tube into the vessel and rise in the other tubes until it was at the same level in all, when it would be in equilibrium. This principle is expressed in the familiar saying, water seeks its level.

EXAMPLE.—The water level in a city reservoir is 150 feet above the level of the street; what is the pressure of the water per square inch on the hydrant?

SOLUTION.— $1 \times 150 \times 12 \times .03617 = 65.106$ lb. per sq. in. Ans.

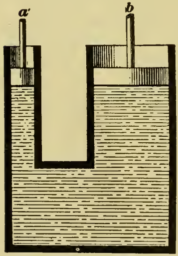


FIG. 9

11. In Fig. 9, let the area of the piston *a* be 1 square inch, of *b* 40 square inches. According to Pascal's law, 1 pound placed on *a* will balance 40 pounds placed on *b*.

Suppose that *a* moves downwards 10 inches; then 10 cubic inches of water will be forced into the tube *b*. This will be distributed over the entire area of the tube *b* in the form of a cylinder, whose cubical contents must be 10 cubic inches, whose base has an area of 40 square inches, and whose altitude must be $\frac{10}{40} = \frac{1}{4}$ inch; that is, a movement of 10 inches of the piston *a* will cause a movement of $\frac{1}{4}$ inch in the piston *b*. The practical application of this principle is shown in the *hydraulic jack*.

12. The Hydraulic Jack.—The **hydraulic jack,** Fig. 10, is hollow and is filled with a mixture of water and alcohol to prevent freezing in cold weather. A lever *a* fits loosely in a socket on the end of the shaft *b*, which is connected by the crank *c* and the rod *g* with the piston *d*. When

the lever *a* is pushed down, the valve *h* is closed by the pressure of the liquid in the space *i* while the valve *j* opens and allows the liquid to pass through *j* into the space *k*; as *k* is

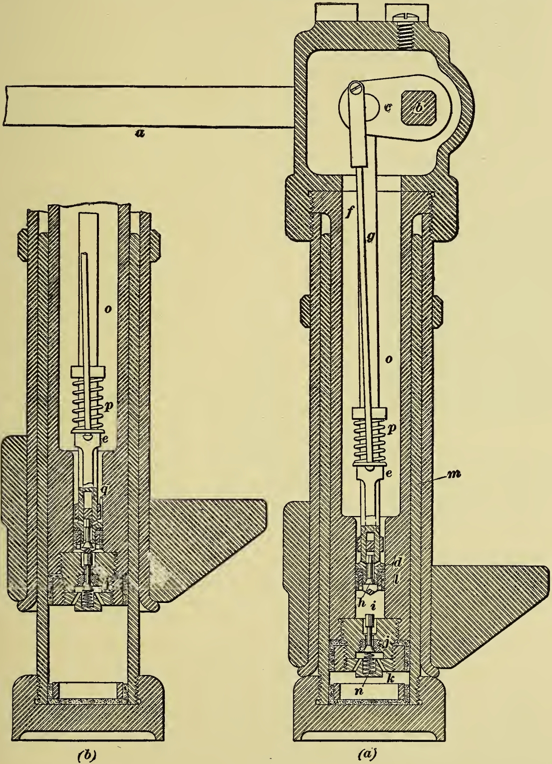


FIG. 10

already filled with liquid, the ram *l*, which slides within the barrel *m*, is lifted. If the lever *a* be raised, valve *h* will be

opened and valve *j* will be closed by the spring *n*, thus preventing the return of water from *k* to *i*, but allowing water to flow from *o* into *i*. By again depressing the piston, the ram is again raised slightly. If the area of the ram is ten times the area of the piston, each pound of pressure on the piston will exert 10 pounds on the ram, and if the length of the lever *a* is ten times the distance from the fulcrum *b* to the piston rod, each pound of pressure on the end of the lever will exert 10 pounds pressure on the piston, or 100 pounds on the ram. But the movement of the ram will be only $\frac{1}{100}$ the movement of the end of the lever.

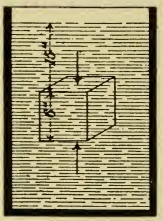


Fig. 11

The ram *l* cannot descend unless valves *h* and *j* are opened to allow the liquid to escape from *k* into *i* and from *i* into *o*. The lever *a* has a projection on the under side so that when it is pressed down its full distance the piston *d* is a short distance above the stem of the valve *j*. If, however, the lever is inserted in its socket with the projection upwards, it can be depressed far enough so that piston *d* opens valve *j*, as shown in Fig. 10 (*b*). At the same time, the spring *p* forces the sleeve *e* downwards and the cotter *q* on the end of the sleeve working in a slot in the piston rod opens the valve *h*.

The sleeve is connected to the top of the valve by the lowering wire *f* in such a manner that the cotter will not strike the valve *h* while the jack is raising the load. The ram can be stopped instantly by raising the lever.

BUOYANT EFFECTS OF WATER

13. In Fig. 11 is shown a 6-inch cube entirely submerged in water. The lateral pressures are equal and in opposite directions. The upward pressure is $6 \times 6 \times 21 \times .03617$; the downward pressure is $6 \times 6 \times 15 \times .03617$; and the difference is $6 \times 6 \times 6 \times .03617$, the volume of the cube in cubic inches $\times$ the weight of 1 cubic inch of water. That is, the upward

pressure exceeds the downward pressure by the weight of a volume of water equal to the volume of the body.

14. This excess of upward pressure acts against gravity; consequently, *if a body be immersed in a fluid, it will lose in weight and amount equal to the weight of the fluid it displaces.* This is called the **principle of Archimedes,** because it was first stated by him.

The principle may be experimentally demonstrated with beam scales, as shown in Fig. 12.

From one scale pan suspend a hollow cylinder of metal *t* and below that a solid cylinder *a*, of the same size as the hollow part of the upper cylinder. Put weights in the other scale pan until they exactly balance the two cylinders. If *a* be immersed in water, the scale pan containing the weights will descend, showing that *a* has lost some of its weight. Now fill *t* with water, and the volume of water that can be poured into *t* will equal that displaced by *a*. The scale pan that contains the weights will gradually rise until *t* is filled, when the scales balance again.

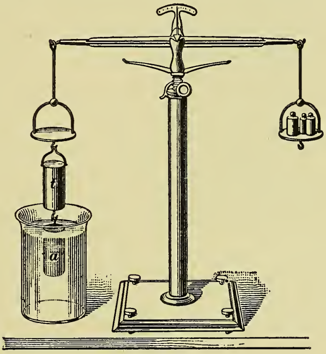


FIG. 12

If the immersed body is lighter than the liquid, the upward pressure will cause it to rise and extend partly out of the liquid, until the weight of the body and the weight of the liquid displaced are equal. If the immersed body is heavier than the liquid, the downward pressure plus the weight of the body will be greater than the upward pressure, and the body will fall until it touches bottom or meets an obstruction. If the weights of equal volumes of the liquid and the body

are equal, the body will remain stationary and be in equilibrium in any position or depth beneath the surface of the liquid.

An interesting experiment in confirmation of the foregoing facts may be performed as follows: Place an egg in a glass jar filled with fresh water. The mean density of the egg being a little greater than that of water, it will fall to the bottom of the jar. Now dissolve salt in the water, stirring it so as to mix the fresh and salt water. The salt water will presently become denser than the egg and the egg will rise. Now, if fresh water is poured in until the egg and water have the same density, the egg will remain stationary in any position that it may be placed below the surface of the water.

HYDRAULICS

15. Hydraulics treats of water in motion. The velocity of the water flowing through a given cross-section of any channel or pipe is not the same at all points of the cross-section, owing to the friction against the sides. The *mean velocity* is the average velocity for the entire cross-section, and, unless otherwise stated, the mean velocity is used in hydraulic problems. The mean velocity is equal to the total quantity discharged divided by the area of the cross-section.

Let Q = quantity, in cubic feet, that passes any section in 1 second;
A = area of section, in square feet;
v = mean velocity, in feet per second.

Then,
$$Q = A v \qquad (1)$$

and
$$v = \frac{Q}{A} \qquad (2)$$

EXAMPLE 1.—The area of a certain cross-section of a stream is 27.9 square inches; the velocity of the water through this section is 51 feet per second. What is the quantity discharged in cubic feet?

SOLUTION.—Applying formula **1**, $Q = \frac{27.9}{144} \times 51 = 9.9$ cu. ft. per sec. Ans.

EXAMPLE 2.—In example 1, what would the velocity have been to discharge the same quantity had the area of the cross-section been 36 square inches?

SOLUTION.—Applying formula 2, $v = \frac{9.9}{\frac{36}{144}} = \frac{9.9 \times 144}{36} = 39.6$ ft. per sec. Ans.

16. Velocity of Efflux.—If a small aperture be made in a vessel containing water, the velocity with which the water issues from the vessel is the same as if it had fallen from the level of the surface to the level of the aperture, all resistances being neglected. This velocity is called the **velocity of efflux.**

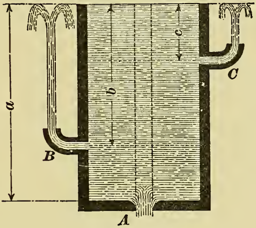


FIG. 13

The vertical height of the level surface of the water above the center of the aperture is called the **head.** In Fig. 13, a is the head for the aperture A; b is the head for the aperture B; and c is the head for the aperture C.

Let v = velocity of efflux, in feet per second;

h = head, in feet, at the aperture considered.

Then, the theoretical velocity of efflux is expressed by the formula

$$v = \sqrt{2gh} \qquad (1)$$

Here $g = 32.16$; that is, the velocity of efflux is the same as if the same weight of water had fallen through a height equal to its head.

Were it not for the resistance of the air, friction, and the effect of the falling particles, the issuing water would spout to the level of the water in the vessel, that is, to a height equal to its head.

EXAMPLE 1.—A small orifice is made in a pipe 50 feet below the water level; what is the velocity of the issuing water?

SOLUTION.—Applying formula 1, $v = \sqrt{2 \times 32.16 \times 50} = 56.7$ ft. per sec. Ans.

From the foregoing formula, as in the laws of falling bodies,

$$h = \frac{v^2}{2g} \qquad (2)$$

Here, h is called the *head due to the velocity v.* Consequently, if the velocity of efflux is known, the head can be found.

EXAMPLE 2.—An issuing jet of water has a velocity of 60 feet per second; what must be the head to give it this velocity?

SOLUTION.—Applying formula 2, $h = \frac{60^2}{2 \times 32.16} = 55.97$ ft. Ans.

17. Suppose that a tall vessel is fitted with a piston and has an orifice near the bottom fitted with a stop-cock. If an additional pressure be applied to the piston, it is evident that the velocity of efflux will be increased.

Let p be the pressure per unit of area at the level of the water, due to the additional pressure on the piston. If the unit of area is 1 square inch, the height of a column of water that will cause a pressure equal to p will be

$$\frac{p}{.03617 \times 12} = \frac{p}{.434} \text{ feet}$$

If the unit of area is in square feet, the height of a column of water will be $\frac{p}{62.5}$ feet. Denote this height corresponding to the additional pressure by h_1. The original head of the water in the vessel is h; hence, $h_1 + h =$ the total head, and the velocity of efflux, when the cock is opened, will be

$$v = \sqrt{2g(h_1 + h)}$$

The total head $h_1 + h$ is called the **equivalent head,** and must in all cases be reduced to feet before substituting in the formula.

EXAMPLE.—The area of a piston fitting a vessel filled with water is 27.36 square inches. The total pressure on the piston is 80 pounds, the weight of the piston is 25 pounds, and the head of the water at the level of the orifice is 6 feet 10 inches; what is the velocity of efflux, assuming that there are no resistances?

SOLUTION.— $80 + 25 = 105$ lb., the total pressure on the upper surface of the liquid. $\frac{105}{27.36} = 3.838$ lb. per sq. in. $\frac{3.838}{.03617} = 106.11$, head,

in inches, due to the pressure of 105 lb. $\frac{106.11}{12} = 8.84$ ft. $= h_1$. 6 ft. 10 in. = 6.8333 ft. $= h$. Hence, applying the formula,

$$v = \sqrt{2g\,(8.84 + 6.8333)} = \sqrt{2 \times 32.16 \times 15.6733} = 31.75 \text{ ft. per sec.}$$

Ans.

18. When water issues from the side of a vessel, it is subjected to the same laws that govern projectiles. The range may be calculated in the same manner by taking the velocity of efflux as the initial velocity of the projectile.

The range may be calculated more conveniently by the formula

$$R = \sqrt{4\,h\,y}$$

in which R = range;

h = head or equivalent head at level of orifice;

y = vertical height of orifice above point where water strikes.

In Fig. 14, the upper surface of the water is free. For the

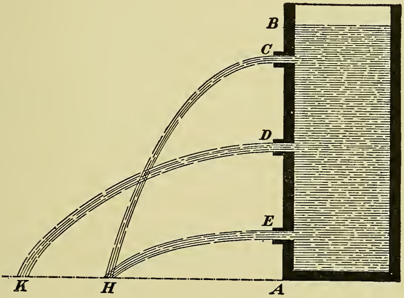


FIG. 14

orifice E, $h = BE$ and $y = EA$; for the orifice C, $h = BC$ and $y = CA$.

The greatest range is obtained when $h = y$; that is, when the orifice is half way between the upper surface of the water and the level of the place where the stream strikes. If two orifices are situated equally distant from the middle orifice

giving the greatest range, as C and E, Fig. 14, the ranges of water issuing from them will be equal.

EXAMPLE.—The vertical height above the ground of the surface of the water in a vessel is 12 feet. If an orifice is situated 4 feet from the upper surface, what is the range? Where is the other point of equal range? What is the greatest range?

SOLUTION.—Applying the formula, $R = \sqrt{4 \times 4\,(12 - 4)} = 11.31$ ft., nearly; greatest range $= \sqrt{4 \times 6 \times 6} = 12$ ft., and $6 - 4 = 2$; hence, the point of equal range is $6 + 2 = 8$ ft. below the surface of the water. Ans.

PROOF.—Range $= \sqrt{4\,h\,y} = \sqrt{4 \times 8 \times 4} = 11.31$ feet, as before.

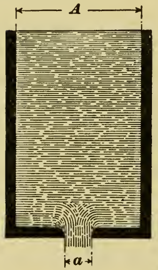


FIG. 15

19. When the water flows through an orifice in the bottom of the vessel and the orifice is of large size compared with the area of the base, a different rule must be used from that given above. In Fig. 15, suppose that the area of the orifice in the bottom of the vessel is a and that the area of the bottom is A; then the velocity v is expressed by the formula

$$v = \sqrt{\frac{2\,g\,h}{1 - \frac{a^2}{A^2}}}$$

If the area of the orifice is not more than one-twentieth of the area of the cross-section of the vessel, use formula **1**, Art. **16**.

EXAMPLE 1.—A vessel has a rectangular cross-section of 11 in. $\times$ 14 in.; the upper surface of the water is 14 feet above the bottom. If an orifice 4 inches square is made in the bottom of the vessel, what will be the velocity of efflux?

SOLUTION.—Area of the cross-section is $14 \times 11 = 154$ sq. in. Area of orifice is $4 \times 4 = 16$ sq. in. $\frac{16}{154} = \frac{1}{9.625}$. Since the area of the orifice is greater than one-twentieth the area of the bottom, apply the formula,

$$v = \sqrt{\frac{2\,g\,h}{1 - \frac{a^2}{A^2}}} = \sqrt{\frac{2 \times 32.16 \times 14}{1 - \frac{16^2}{154^2}}} = 30.17 \text{ ft. per sec. Ans.}$$

EXAMPLE 2.—(*a*) If the orifice had been 2 inches square in example 1, what would have been the velocity of efflux? (*b*) If it had been 8 inches square?

SOLUTION.—(*a*) $2 \times 2 = 4$ sq. in., area of the orifice. $\frac{4}{154} = \frac{1}{38.5}$. Since the area of the orifice is less than one-twentieth the area of the vessel, apply formula **1**, Art. **16**,

$$v = \sqrt{2gh} = \sqrt{2 \times 32.16 \times 14} = 30.008 \text{ ft. per sec. Ans.}$$

(*b*) $8 \times 8 = 64$ sq. in., the area of the orifice in the second case; then, applying the formula in Art. **19**,

$$v = \sqrt{\frac{2gh}{1 - \frac{a^2}{A^2}}} = \sqrt{\frac{2 \times 32.16 \times 14}{1 - \frac{64^2}{154^2}}} = 32.99 \text{ ft. per sec. Ans.}$$

20. The Contracted Vein.—When water issues from an orifice in a thin plate (Fig. 16) or from a square-edged

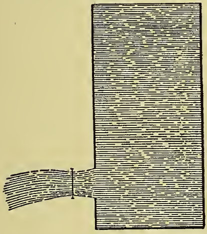


FIG. 16

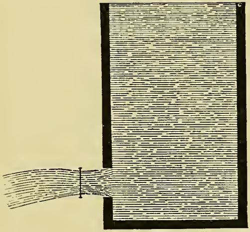


FIG. 17

orifice (Fig. 17), the stream is contracted a short distance from the orifice and expands again to the full size of the orifice. The point at which the contraction is greatest is at a distance from the orifice equal to the diameter of the orifice. In consequence of this contraction, the velocity of efflux is slightly reduced from the theoretical value and the quantity discharged is greatly reduced. This contraction is called the **contracted vein**, or *vena contracta*, a name given to it by Sir Isaac Newton.

For ordinary purposes, the actual velocity of efflux may be taken as 98 per cent. of the theoretical values calculated by the preceding rules.

The actual velocity of efflux from a small orifice is expressed by the formula

$$v = .98\sqrt{2\,g\,h}$$

EXAMPLE.—What is the actual velocity of discharge from a small, square-edged orifice in the side of a vessel, if the head is 20 feet?

SOLUTION.—Applying the formula,

$v = .98\sqrt{2\,g\,h} = .98\sqrt{2 \times 32.16 \times 20} = 35.15$ ft. per sec. Ans.

21. The diameter of the contracted vein at its smallest section is about .8 of the diameter of the orifice and its area is about $.8 \times .8 = .64$ of the area of the orifice. In Art. **15,** it was stated that the quantity discharged, in cubic feet per second, is equal to the area of the section multiplied by the mean velocity, or $Q = A\,v$. This is the theoretical value; the actual value is the area of the contracted vein multiplied by the actual velocity of efflux, or $Q = .64\,A \times .98\,v = .627\,A\,v$; that is, the actual discharge is about .627 of the theoretical discharge. This number .627 is called the **coefficient of efflux.**

The coefficient of efflux varies somewhat according to the head and the size and shape of the orifice; but for square-edged orifices or for orifices in thin plates, its average value may be taken as .615. Hence,

Rule.—*The actual quantity discharged is .615 times the theoretical amount,*

or $$Q = .615\,A\,v$$

EXAMPLE.—The theoretical discharge from a certain vessel is 12.4 cubic feet per minute; what is the amount actually discharged per second?

SOLUTION.— $12.4 \times .615 = 7.626$ cu. ft. per min.; $\frac{7.626}{60} = .1271$ cu. ft. per sec. Ans.

22. If the water discharges through a short tube, whose length is from $1\frac{1}{2}$ to 3 times the diameter of the orifice (see Fig. 18), the discharge will be increased. From a large number of experiments made by different persons, the coefficient of efflux for a short tube may be taken as .815; that is, the actual discharge may be taken as .815 times

the theoretical discharge through an orifice of the same size. If the inside edges of the tube are well rounded and the tube is conical, as shown in Fig. 19, there will be no contraction, and the coefficient of discharge may be taken

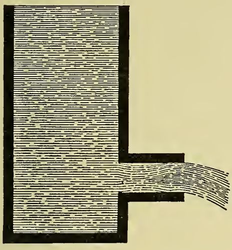


FIG. 18

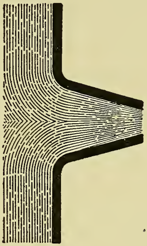


FIG. 19

as .97; that is, the actual discharge through a tube of this form will be .97 times the theoretical discharge through an orifice whose area is the same as the area of the end of the tube.

23. If in a compound mouthpiece or tube, such as is shown in Fig. 20, the narrowest part *a b* be taken as the diameter of the orifice, the coefficient of discharge may be taken as 1.5526; that is, the actual discharge through a compound mouthpiece of this shape will be 1.5526 times the theoretical discharge through an orifice whose area is the same as the area of the smallest section of the mouthpiece.

FIG. 20

When the upper surface of the water remains at the same height above the orifice, there is said to be a *constant head*. The velocity of efflux varies for different points in the orifice; it is greater at the bottom of the orifice than at the top, since the head is greater at the bottom. The mean velocity

may be obtained by dividing the quantity of water discharged, in cubic feet per second, by the area of the orifice; or

$$v = \frac{Q}{A} \quad \text{(See formula } \mathbf{2}\text{, Art. } \mathbf{15}\text{)}$$

24. Let Q = theoretical number of cubic feet discharged per second;

v = mean velocity through orifice, in feet per second;

A = area of orifice, in square feet;

h = theoretical head necessary to give a mean velocity v;

Q_a = actual quantity discharged, in cubic feet per second.

Then, for an orifice in a thin plate or a square-edged orifice (the hole itself may be of any shape—triangular, square, circular, etc.—but the edges must not be rounded), the actual quantity discharged is

$$Q_a = .615\ Q = .615\ A v = .615\ A\sqrt{2gh} \qquad (1)$$

For a discharge through a short tube, as shown in Fig. 18,

$$Q_a = .815\ Q = .815\ A v = .815\ A\sqrt{2gh} \qquad (2)$$

For a discharge through a mouthpiece, as shown in Fig. 19,

$$Q_a = .97\ Q = .97\ A v = .97\ A\sqrt{2gh} \qquad (3)$$

For a discharge through the compound mouthpiece, as shown in Fig. 20, the area of the orifice being taken as the area of the smallest section,

$$Q_a = 1.5526\ Q = 1.5526\ A v = 1.5526\ A\sqrt{2gh} \qquad (4)$$

In these four formulas it is assumed that the head remains constant.

FLOW OF WATER THROUGH PIPES

THE HYDRAULIC GRADE LINE

25. The **hydraulic grade line,** or **hydraulic gradient,** is the line drawn through a series of points to which water will rise in tubes attached to a pipe through which water flows. With a smooth pipe of uniform cross-section

without bends or other obstructions to flow, it is a straight line extending from a point slightly below the surface of the water in the reservoir to the end of the pipe.

In Fig. 21 is shown a long horizontal pipe leading from a reservoir to a stop-valve S. When the valve is open so that water from the pipe discharges freely into the atmosphere, the hydraulic grade line is the line $a\,d\,fg$. The distance of the point a below the surface of the water in the reservoir represents the head absorbed in overcoming the resistances of entrance to the pipe and in producing the velocity with

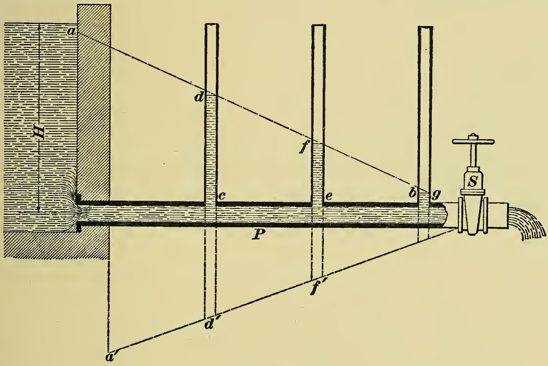


FIG. 21

which the water flows. In the same way, the difference in the height to which the water rises in any two tubes represents the head absorbed in overcoming the resistance to flow in the pipe between the points at which the tubes are joined.

The flow of water through the pipe P would be the same, except for the difference due to the different lengths of the pipe, whether the pipe were horizontal, as shown, or laid along the grade line $a\,d\,f\,g$; or, if the reservoir were deepened and the pipe laid along the line $a'\,d'\,f'$. The pressures in the pipe, however, would vary greatly with the different positions. If it were laid along the line $a\,d\,f\,g$, there would be little or no pressure in any part of it, and if it were perforated

at the top, little or no water would flow from the perforations. In the horizontal position, however, and still more in the position $a' d' f'$, there would be pressure at all points, the pressure for any point in the pipe being equivalent to the head represented by the vertical distance from that point to the hydraulic grade line; and if the pipe were perforated anywhere, water would issue from the perforations.

26. In laying a line of pipe to connect two points having different elevations, it is of the utmost importance to ascertain the position of the hydraulic grade line. Let A and B, Fig. 22, represent two reservoirs connected by a pipe line

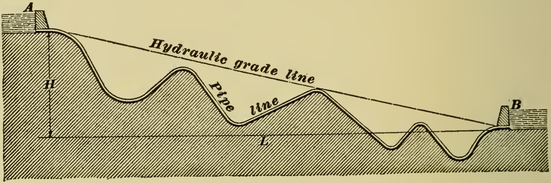


FIG. 22

of uniform diameter through which the water flows by gravity from the upper to the lower level. The hydraulic grade line will be the straight line connecting the two reservoirs; in order to cover the most unfavorable conditions, it is usually drawn between the two ends of the pipe line, and not from surface to surface of the water in the two reservoirs, as the level of these surfaces may vary. The slope of the grade line will be represented by $\frac{H}{L}$. In order that the discharge may take place under the full head, the pipe line must never rise above the grade line at any point.

Should the pipe rise above this grade line, as is shown at b, Fig. 23, the rate of slope is no longer $\frac{H}{L}$ through the entire pipe line, but it is broken into two others at the point b, one $\frac{h}{l}$ flatter and the other $\frac{h'}{l'}$ steeper than $\frac{H}{L}$. If the pipe were of the same diameter throughout, it would not discharge

as much water as if it were kept entirely under the hydraulic grade line *a c*, because its flow would be governed by the flatter hydraulic grade line *a b*. From *b* to *c* the water would flow without completely filling the pipe. Sometimes, when a rocky ridge must be crossed, where it would be very difficult and expensive to keep the pipe low enough, two diameters are used; the larger one being laid between *a* and *b* and the smaller between *b* and *c*. By properly proportioning the diameters to the grades, according to the

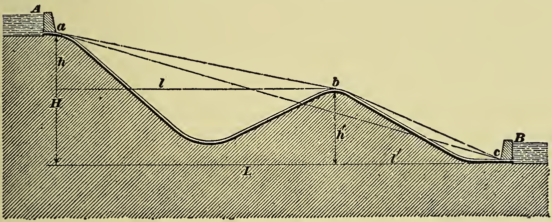


Fig. 23

rules for the flow of water through pipes, the desired discharge can be economically secured.

FLOW OF WATER THROUGH LONG PIPES

27. When comparing the length of pipe with head or pressure, the diameter of the pipe and the nature of its interior surface are so much more important than the head h, which is the only factor considered in the formula $v = \sqrt{2gh}$, that this formula is not used in connection with a long pipe. The velocity of flow and consequent volume of discharge through pipes of different diameters and under different circumstances can be found only by direct experiment.

DARCY'S FORMULAS

28. The French engineer Darcy made a series of experiments with pipes of different diameters, from which he formulated certain algebraic expressions that have remained

standard. It was found by these experiments that the character of the interior surface of the pipe affected, to a remarkable degree, the velocity of the water flowing through it. The amount of water flowing with a given head through a clean, smooth pipe of given diameter and length was surprisingly diminished when another pipe, exactly similar, except having a rough and dirty interior surface, was substituted. The degree of reduction in this case was surprising because it had been supposed that the small projections caused by the roughness of the surface would, at most, only affect the flow by diminishing to that extent the inside diameter of the pipe. This would be the case if water were a perfect fluid, for then some of the particles of water would simply level up the irregularities of the surface and the other particles would flow freely over them. Water, however, is very far removed from a perfect fluid. It possesses the property of viscosity to a great degree, and the particles of which it is composed, instead of moving freely over one another, are held together by molecular attraction, and it requires considerable force to tear them apart. For this reason, the term "friction" is misapplied when used to express the resistance experienced by water in flowing over a rough surface. It is really a resistance to shearing that takes place.

29. It has been found, within the extreme limits of roughness and smoothness that exist in practice, that if a smooth pipe of given diameter discharges a certain quantity of water per second, a rough pipe, otherwise similar, will require a diameter 15 per cent. greater to discharge the same amount in the same time. Thus, if the smooth pipe has a diameter of 36 inches, the rough pipe will require one of 41.40 inches to have an equal delivery. Did not this fact rest on actual experience, it would seem incredible that irregularities amounting to only a fraction of 1 per cent. of the diameter of a pipe could affect the flow to such an extent. It is explainable, however, the moment the great viscosity of water is realized.

These facts led Darcy to divide cast-iron water pipes into the two classes already mentioned, *smooth* and *rough*, the formula for the flow through each being modified by an appropriate coefficient. The cleanest and best-conditioned pipes will not give a greater discharge than that assigned to them by the coefficient for smooth pipes, nor will the greatest amount of roughness, from the incrustations to which pipes are liable in practice, reduce the flow below that for rough pipes, although it frequently approaches it closely.

30. Fundamental Formula.—Darcy's formula for long pipes, by which is understood pipes of 1,000 diameters and over in length, is

$$\frac{DH}{CLv^2} = 1 \qquad (1)$$

in which D = diameter of pipe, in feet;
H = total head, in feet;
L* = total length, in feet;
v = velocity of efflux, in feet per second;
C = an experimental coefficient.

From formula **1**,

$$v = \sqrt{\frac{DH}{CL}} \qquad (2)$$

Since the quantity Q, in cubic feet per second, is equal to the area A of the pipe, in square feet, multiplied by the velocity, in feet per second,

$$Q = A\sqrt{\frac{DH}{CL}} \qquad (3)$$

Since $A = .7854\ D^2$,

$$Q = .7854\ D^2\sqrt{\frac{DH}{CL}} \qquad (4)$$

which may be written

$$Q = \sqrt{\frac{.617\ D^5\ H}{CL}} \qquad (5)$$

*Although L is, properly speaking, the actual length of the pipe, it differs in practice so little from its horizontal projection that the latter is taken as being, in general, a sufficiently close approximation.

31. Coefficients.—The important matter now is to know the value of C. For this, Darcy gives the following table, based on his experiments.

It will be observed that the coefficient for smooth pipes is in all cases half that of rough ones. As all pipes, no matter how clean and smooth they may be when first laid, become,

TABLE I

TABLE OF COEFFICIENTS

Diameters in Inches	Value of C for Rough Pipes	Value of C for Smooth Pipes
3	.00080	.00040
4	.00076	.00038
6	.00072	.00036
8	.00068	.00034
10	.00066	.00033
12	.00066	.00033
14	.00065	.00033
16	.00064	.00032
24	.00064	.00032
30	.00063	.00032
36	.00062	.00031
48	.00062	.00031

in course of time, more or less incrusted, it is safer, in practice, to always use the coefficient for rough pipes when a permanent system is being laid down.

32. It will be noticed, from Table I, that the coefficients for pipes from 8 to 48 inches in diameter do not greatly vary; moreover, from formulas **3**, **4**, or **5**, Art. **30**, all other conditions being equal, the quantity discharged is affected by only the square root of the coefficient, so that slight differences in its value are insignificant in reference to the volume of water discharged. Formula **5**, Art. **30**, contains the factor .617, and if .000617 be taken as an approximate

coefficient for pipes within limits of 8 and 48 inches, the formula becomes

$$Q = \sqrt{\frac{.617\ D^5\ H}{.000617\ L}}$$

whence, $$Q = \sqrt{\frac{1{,}000\ D^5\ H}{L}} \qquad (1)$$

If, now, for $\frac{H}{L}$, or the total head divided by the total length of pipe, the head per thousand, or $\frac{h}{1{,}000}$, be substituted, this formula becomes

$$Q = \sqrt{D^5\ h} \qquad (2)$$

which may be generalized thus:

$$\frac{Q^2}{h\ D^5} = 1 \qquad (3)$$

In this formula, it must be borne in mind that h is the fall per thousand. When logarithms are used, formulas **1** and **2** are readily solved. Otherwise, they may be more conveniently written:

$$Q = D^2 \sqrt{D\ h} \qquad (4)$$

$$\frac{Q}{D^2 \sqrt{D\ h}} = 1 \qquad (5)$$

For pipes of smaller diameter, from 3 to 6 inches, .000785 is assumed as a coefficient. Then, from formula **5**, Art. **30**,

$$Q = \sqrt{\frac{.785 \times .785\ D^5\ H}{.000785\ L}}$$

whence, $$\frac{Q^2}{h\ D^5} = .785 \qquad (6)$$

also $$Q = .89 \sqrt{D^5\ h} \qquad (7)$$

That is to say, for these smaller diameters, the delivery will be, in round numbers, about 90 per cent. of that given by formula **2**, Art. **32**.

33. Formulas for Smooth Pipes.—While in practice the formulas for rough pipes should always be used, it is sometimes useful to know the probable discharge through smooth ones. Since the coefficients for the latter are always

one-half of those of the former, for smooth pipes formulas **2** and **3**, Art. **32**, may be written,

$$Q = \sqrt{2\,D^5\,h} \qquad (1)$$

$$\frac{Q^2}{h\,D^5} = 2 \qquad (2)$$

Also, from formula **1**,

$$Q = 1.40\sqrt{D^5\,h} \qquad (3)$$

That is to say, *in general, the discharge through a smooth pipe is 1.40 times that through a rough pipe of the same diameter; and reciprocally, the discharge through a rough pipe is .70 times that through a smooth one of the same diameter.* These factors represent the practical limits between which the extremes of roughness and smoothness can affect the flow through long pipes.

34. Formulas for Velocity.—Formulas for velocity may be derived from those already established.

Since velocity is equal to quantity divided by area, there is obtained from formula **4**, Art. **32**, for rough pipes of from 8 to 48 inches diameter,

$$v = \frac{D^2\sqrt{D\,h}}{.7854\,D^2}$$

whence,

$$v = 1.27\sqrt{D\,h} \qquad (1)$$

For rough pipes of smaller diameter,

$$v = 1.13\sqrt{D\,h} \qquad (2)$$

For smooth pipes of large diameter,

$$v = 1.78\sqrt{D\,h} \qquad (3)$$

For smooth pipes of small diameter,

$$v = 1.60\sqrt{D\,h} \qquad (4)$$

The ratio of the velocities will be as the quantities; hence, the general rule in Art. **33** holds good for relative velocities also.

The terms rough and smooth here, as elsewhere, signify the extremes of both cases.

EXAMPLE 1.—A rough pipe 16 inches in diameter and 3,700 feet long connects two reservoirs, the difference of elevation between the

two being 187 feet; with what velocity does the water flow through the pipe?

SOLUTION.—Substituting in formula **2**, Art. **30**,

$$v = \sqrt{\frac{\frac{4}{3} \times 187}{.00064 \times 3{,}700}} = 10.26 \text{ ft. per sec. Ans.}$$

EXAMPLE 2.—What is the velocity through the pipe in example 1 calculated by formula **1**, Art. **34**?

SOLUTION.— $v = 1.27\sqrt{\frac{4}{3} \times 50.5} = 10.42$ ft. per sec. Ans.

NOTE.—In approximate formulas, such as all those that apply to the flow of water through pipes necessarily are, the results obtained in examples 1 and 2 are equivalent to an agreement, and in practice one might happen to be as nearly right as the other. It is obvious that when the character of the pipe may vary as to interior surface so widely, a very close result can never be hoped for, and all that can be done is to keep within probable limits.

EXAMPLE 3.—A rough iron pipe 10 inches in diameter is laid with a fall of $7\frac{1}{2}$ feet per 1,000 feet; what is the discharge?

SOLUTION.—According to formula **2**, Art. **32**, $Q = \sqrt{D^5 h}$. Substituting the values in the above example, $(\frac{10}{12})^5$ for D^5 and $7\frac{1}{2}$ for h, the formula becomes, $Q = \sqrt{\frac{3{,}125}{7{,}776} \times 7\frac{1}{2}}$. Performing the indicated operations, $\sqrt{\frac{3{,}125 \times 7\frac{1}{2}}{7{,}776}} = \sqrt{3.01} = 1.736$, which is the discharge in cubic feet per second. Ans.

EXAMPLE 4.—It is desired to discharge 3 cubic feet per second from a pipe line having a fall of 5 feet per 1,000 feet; what diameter of rough cast-iron pipe will be required?

SOLUTION.—Insert the data given in formula **3**, Art. **32**. Then, $D = \sqrt[5]{\frac{9}{5}} = \sqrt[5]{1.8} = 1.125$ ft., or $13\frac{1}{2}$ in., diameter. Ans.

As cast-iron pipes are made only in full inch sizes, the nearest approach to the size would be a pipe 14 in. in diameter. It is usual for hydraulic engineers to provide themselves with tables, for the purpose of working such intricate examples as occur in this subject. Some, however, extract the roots by logarithms. Others provide themselves with tables containing fifth roots and their corresponding numbers. The extraction of the fifth root of numbers is very long and tedious, and the student is referred to the *Arithmetic* for the method of solving such examples.

EXAMPLE 5.—It is desired to discharge $\frac{1}{2}$ cubic foot per second from a 4-inch pipe; what head per 1,000 is necessary to accomplish this?

SOLUTION.—Substituting the data in formula **6**, Art. **32**,

$$h = \frac{\frac{1}{4}}{.785 \times \frac{1}{243}} = 77.39 \text{ ft. Ans.}$$

35. General Relations Between D, Q, L, H, and C, and D', Q', L', H', and C'.—From formula **1**, Art. **30**, we have for a given pipe line

$$\frac{DH}{CLv^2} = 1$$

For any other system, $\frac{D'H'}{C'L'v'^2} = 1$ and $\frac{DHC'L'v'^2}{D'H'CLv^2} = 1$.

C and C' will generally be sufficiently near each other to be negligible; hence,

$$\frac{DHL'v'^2}{D'H'Lv^2} = 1 \qquad (1)$$

Also, from formula **5**, Art. **30**, there results, $\frac{Q^2L}{D^5H} = \frac{.617}{C}$ and $\frac{Q'^2L'}{D'^5H'} = \frac{.617}{C'}$. Then, letting $C = C'$,

$$\frac{Q^2LD'^5H'}{Q'^2L'D^5H} = 1 \qquad (2)$$

Example.—A pipe 16 inches in diameter, 3,700 feet long, with a total fall of 187 feet, has a velocity of 10.26 feet per second; another pipe has exactly the same elements, except that its diameter is 18 inches; what is its velocity?

Solution.—Let the elements of the first pipe be D, H, L, and v, and those of the second, D', H', L', and v'. By the conditions given, $H = H'$ and $L = L'$. Then, in formula **1**, $\frac{Dv'^2}{D'v^2} = 1$, and $v' = v\sqrt{\frac{D'}{D}}$. Substituting the data,

$$v' = 10.26\sqrt{\frac{1.50}{1.33}} = 10.83 \text{ ft. per sec. Ans.}$$

36. From formula **2**, Art. **35**, $Q' = \sqrt{\frac{Q^2LD'^5H'}{L'D^5H}}$. If L and H equal, respectively, L' and H', then

$$\frac{Q'}{Q} = \sqrt{\frac{D'^5}{D^5}} \qquad (1)$$

That is, other elements being equal, the quantities discharged are as the square roots of the fifth powers of the diameters. This is a very important relation.

Example 1.—A long pipe 24 inches in diameter gives a discharge of 2 cubic feet per second; what will be the discharge of a pipe under similar circumstances 30 inches in diameter?

Solution.—By multiplying formula **1** by Q and canceling, Q', which represents the quantity of water that will be discharged, is obtained as follows: $Q' = Q\sqrt{\frac{D'^5}{D^5}}$. By substitution,

$$Q' = 2\sqrt{\frac{(2.5)^5}{(2)^5}} = 2\sqrt{(1.25)^5} = 2\sqrt{3.052}$$

$= 1.747 \times 2 = 3.494$ cu. ft. discharged per second. Ans.

Example 2.—A 24-inch pipe discharges 2 cubic feet per second; what diameter pipe, with the same length and head, will be required in order to discharge 3 cubic feet per second?

Solution.—The length of the pipe and the head being the same for both pipes, they may be neglected and the formula $D' = D\sqrt[5]{\frac{Q'^2}{Q^2}}$ may be obtained from formula **1**, by taking D'^5 and D^5 from under the square-root sign and placing Q'^2 and Q^2 under the fifth-root sign. Then, by the substitution of the given data in this formula, the diameter D', which represents the diameter of the pipe sought, may be found as follows:

$$D' = 2\sqrt[5]{\frac{9}{4}} = 2 \times 1.176 = 2.352 \text{ ft. in diameter, or } 12'' \times 2.352' = 28.224 \text{ in.}$$

This would probably be taken in practice as 28 in., for the next regular size of cast-iron pipe is 30 in., which is much larger than needed. Ans.

The difference in area between 28-in. and 30-in. diameter pipes is 91 sq. in., or nearly $\frac{3}{4}$ sq. ft. The rules given in this Section are only approximate, and with pipes from 6 to 24 in. in diameter are liable to vary from 5 to 15 per cent. The formulas given are the textbook standards, but as stated are not absolutely correct.

Example 3.—A 24-inch pipe, as in example 1, discharges 2 cubic feet per second; how many 8-inch pipes will be required to give the same discharge, the heads and lengths being the same?

Solution.—Let x = the required pipes. Then the number required being inversely as the quantity discharged, invert formula **1**, and obtain

$$x = \sqrt{\frac{D^5}{D'^5}} \qquad \textbf{(2)}$$

Inserting the data, $x = \sqrt{\frac{2^5}{(\frac{2}{3})^5}} = \sqrt{3^5}$; $x = \sqrt{3^3 \times 3^2} = 3\sqrt{27} = 15.588$.

That is to say, sixteen pipes would be required, each 8 in. in diameter. Ans.

The student is again reminded that all the preceding formulas apply to long pipes only; i. e., those whose length is at least 1,000 times the diameter.

FLOW OF WATER THROUGH SHORT PIPES

37. All that precedes refers to the flow of water through long, rough pipes, where only the head necessary to maintain the flow against the interior resistance of the pipe has been taken into account. In such pipes, the additional head necessary to overcome resistance to entry into the pipe and that necessary to produce the velocity of flow are so insignificant in comparison with the so-called friction head that they are neglected as unnecessarily complicating the formulas.

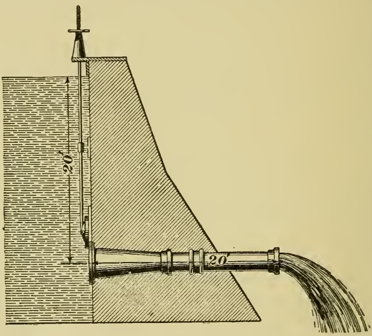


FIG. 24

In short pipes, however, the case is quite different, and the velocity and entrance heads must be taken into account. For this purpose, take the entrance head at about one-half the velocity head.

Suppose, for example, that a reservoir, Fig. 24, is tapped by a 24-inch pipe 20 feet long, the center of which is 20 feet below the surface of the water in the reservoir. What is the discharge, using formulas for rough pipe and ignoring the modifying action of the reducers shown in the figure?

What is wanted here is the velocity of efflux, which can be obtained in the following manner:

The total head, 20 feet, is made up of the velocity head, the entrance head, and the frictional head. Call the velocity

head x, and the entrance head will then be $\frac{x}{2}$. The frictional head call y. Then, $\frac{3x}{2} + y = 20$. The velocity head is that required by the law of falling bodies, $x = \frac{v^2}{2g}$. The velocity and entrance heads together, are, therefore, $\frac{3v^2}{4g}$.

From formula **1**, Art. **34**,

$$v = 1.27\sqrt{D \times \frac{1{,}000\,y}{L}}$$

where h is replaced by its value $\frac{1{,}000\,y}{L}$. Substituting the given data,

$$v = 1.27\sqrt{2 \times \frac{1{,}000\,y}{20}}, \text{ and therefore } y = \frac{v^2}{161}.$$

From $\frac{3x}{2} + y = 20$, by substituting $\frac{v^2}{2g}$ for x, and $\frac{v^2}{161}$ for y (neglecting small decimals), $v^2\left(\frac{3}{129} + \frac{1}{161}\right) = 20$. $v^2 = \frac{6{,}923}{204} \times 20 = 678.7$; $v = 26.05$ feet per second. Area of 2-foot pipe $= 3.1416$ square feet. Then the discharge is equal to the area of cross-section of the pipe multiplied by the velocity, and $Q = 26.05 \times 3.1416 = 81.84$ cubic feet per second.

38. The formula for finding the diameter of a short pipe to convey a given quantity of water with a given head is derived from the general formula as follows:

Solving the form of formula **1**, Art. **34**, given in the last article for y, $y = \frac{v^2 L}{1612.9\,D}$; this substituted in the expression for the total head,

$$H = \frac{3v^2}{4g} + y, \text{ gives } H = \frac{3v^2}{4g} + \frac{v^2 L}{1612.9\,D}$$

Substituting for v its value $\frac{Q}{.7854\,D^2}$, and reducing,

$$H = \frac{Q^2}{26.45\,D^4} + \frac{Q^2 L}{995\,D^5} \qquad (1)$$

from which

$$D = .251\sqrt[5]{\frac{Q^2}{H}(37.6\,D + L)} \qquad (2)$$

To use this formula, first assume a value for the D under the radical sign and solve, thus finding an approximate value for D. Then substitute this new value for the D under the radical and solve again, and if the new value of D agrees closely with the first approximation, the next larger commercial size may be taken as the required size of pipe. If, however, the second value differs greatly from the first approximation, it may be substituted for the D under the radical and a new value can thus be found. One or two approximations of this kind will usually give a value of D that will enable one to select the commercial size nearest to the theoretical diameter.

EXAMPLE.—What diameter of pipe must be used in order to draw 17.22 cubic feet of water per second from a reservoir if the total head is 20 feet and the pipe is 20 feet long?

SOLUTION.—Assuming for D a value of 16 in. = 1.33 ft. and substituting it for the D under the radical in formula **2**,

$$D = .251\sqrt[5]{\frac{17.22^2}{20}(37.6 \times 1.33 + 20)} = 1.0067 \text{ ft., say 1 ft.}$$

Substituting this value under the radical,

$$D = .251\sqrt[5]{\frac{17.22^2}{20}(37.6 \times 1 + 20)} = .968 \text{ ft.}$$

Since this value is so near that of the first approximation, it is plain that the required diameter is 1 ft. Ans.

OTHER LOSSES OF HEAD

39. Besides the losses of head that have been considered, there are minor ones, such as those occasioned by bends, changes of grade, or by passing from one diameter to another. In general, any such changes in a pipe line produces some loss of head, but all such that occur in practice are so insignificant in comparison with the loss of head from interior surface resistance that no account is taken of them. In practice, changes of horizontal direction, when at all pronounced, are effected by special castings called *bends*, which effect the change with very little loss of head; and changes of diameter are made through other special castings, called *reducers*, tapering in form, so as to mold the stream of water

into the proper shape for entering into the pipe of different diameter. Moreover, since water pipes are always cast to even sizes, when calculation calls for a fractional diameter, as it almost always does, the next larger size of even inches

FIG. 25

FIG. 26

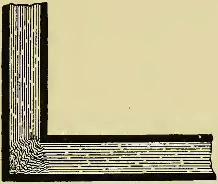


FIG. 27

is taken, and this is generally more than enough to cover all the small losses that can occur from the foregoing causes.

When bends and elbows are necessary, they should be as large as circumstances will permit, so as to change the direction gradually. Sudden changes in direction reduce the velocity very rapidly, and, consequently, reduce the discharge. A reduction or increase in the size of the pipe, such as connections with smaller or larger branch pipes, also reduces the velocity in the main line.

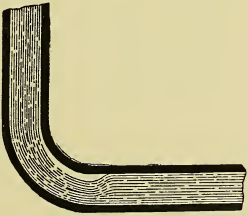


FIG. 28

Bends should be rounded as shown in Fig. 25, rather than sharp, as shown in Fig. 26. A right-angled elbow, as shown in Fig. 27, is very destructive to the velocity, and wherever a 90-degree turn must be made, a rounded elbow, as in Fig. 28, should be used, with the radius made as large as possible.

FLOW OF WATER THROUGH OPEN CHANNELS

40. The **amount of water** flowing through an open channel is found by formula **1**, Art **15**, $Q = A\,v$, but the velocity v depends on the character of the sides and bottom of the channel and the slope is found approximately by the following formulas:

For channels with earthen banks,

$$v = r\sqrt{\frac{100{,}000\,s}{9\,r + 35}} \qquad \textbf{(1)}$$

For channels lined with dry stone work,

$$v = r\sqrt{\frac{100{,}000\,s}{8\,r + 15}} \qquad \textbf{(2)}$$

For channels lined with rubble masonry,

$$v = r\sqrt{\frac{100{,}000\,s}{7.3\,r + 6}} \qquad \textbf{(3)}$$

For channels lined with wood or brick,

$$v = r\sqrt{\frac{100{,}000\,s}{6.6\,r + .46}} \qquad \textbf{(4)}$$

in which v = mean velocity of flow, in feet per second;

r = hydraulic radius $= \frac{A}{p}$;

A = area of water cross-section, in square feet;

p = wet perimeter, or that portion of outline of cross-section of stream in contact with channel, in feet;

s = slope = ratio $\frac{H}{L}$ = tangent of slope;

H = difference in level between ends of channel or ditch, or between two points under consideration;

L = horizontal length of portion of channel under consideration.

EXAMPLE.—Referring to Fig. 29 (a), what is the velocity of flow in a timber-lined channel when $a\,b$ = 26 feet; $c\,d$ = 16 feet; $a\,c$ and

bd = 10 feet each; and e = 9 feet; and the slope equals 1 foot in 1,000 feet?

SOLUTION.—

$$A = \frac{ab + cd}{2} \times e = \frac{26 + 16}{2} \times 9 = 189 \text{ sq. ft.}$$

$$p = ac + cd + db = 10 + 16 + 10 = 36 \text{ ft.}$$

$$r = \frac{A}{p} = \frac{189}{36} = 5.25$$

$$s = \tfrac{1}{1000} = .001$$

Substituting these values in formula 4,

$$v = r\sqrt{\frac{100{,}000\,s}{6.6\,r + .46}} = 5.25\sqrt{\frac{100{,}000 \times .001}{6.6 \times 5.25 + .46}} = 5.25\sqrt{\frac{100}{35.11}}$$

$$= 8.86 \text{ ft. per sec. Ans.}$$

41. If the channel or conduit is entirely enclosed, as in Fig. 29 (b), and is running full of water, but not under pressure, the formulas in Art. **40** apply. If the water is under pressure, the formulas for pipes must be used. In the case of an unlined mine-drainage tunnel, it is difficult to accurately determine the area and wet perimeter owing to the irregularity of the rock sides and in such a case it is best to take average dimensions for the tunnel and take 85 to 90 per cent. of the amount of water that would flow through a brick-lined tunnel of the same size.

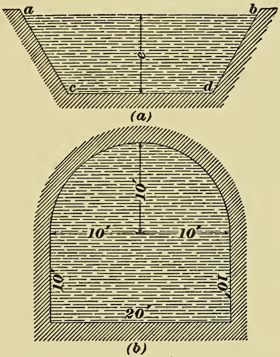


FIG. 29

42. The velocity of flow through a pipe or conduit is determined by means of various meters or gauges or by direct measurement. The greatest velocity of current occurs at a point some distance below the surface in the deepest part of the channel. Fairly accurate results may be obtained by determining the velocity of the current at various points in a carefully surveyed cross-section of the stream. It is frequently advantageous to divide the stream into sections

and determine the mean velocity and flow in each section. The points for observation should be chosen where the channel is comparatively straight and the current uniform. Surface floats may be used and the mean velocity of the section where the float is used will then be nine-tenths of the surface velocity. The total amount of water flowing in the stream will be the sum of the amounts in each section. The average velocity of the entire stream may be found by dividing the total amount of water flowing by the total area of the cross-section of the stream.

43. Size of Channel.—It is often necessary to determine the dimensions of a wooden channel or flume to carry a given quantity of water. The following example shows an approximate method of doing this:

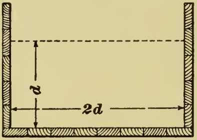


FIG. 30

EXAMPLE.—Find the dimensions of a wooden flume to carry 250 cubic feet of water per second with a grade of $8\frac{1}{2}$ feet per mile, the width of the flume to be twice the depth of the water flowing through it.

SOLUTION.—In Fig. 30, if the depth of water in the flume is represented by d; the width will be $2d$; the wet perimeter p will be $4d$; the area A of the water cross-section will be $2d \times d = 2d^2$; the hydraulic radius r will be $\frac{A}{p} = \frac{2d^2}{4d} = \frac{d}{2}$. The slope s is $\frac{8.5}{5,280} = .0016$; the mean velocity v is $\frac{250}{A} = \frac{250}{2d^2} = \frac{125}{d^2}$; substituting these values in formula 4, Art. 40, $v = r\sqrt{\frac{100,000\,s}{6.6\,r + .46}}$, we have, $\frac{125}{d^2} = \frac{d}{2}\sqrt{\frac{100,000 \times .0016}{6.6 \times \frac{d}{2} + .46}}$ $= \frac{d}{2}\sqrt{\frac{160}{3.3\,d + .46}}$, or expressed as an equation, $\frac{125}{d^2} = \frac{d}{2}\sqrt{\frac{160}{3.3\,d + .46}}$; squaring both sides of the equation $\frac{15,625}{d^4} = \frac{40\,d^2}{3.3\,d + .46}$; $d^6 - 1,289\,d = 179.7$.

Assuming a depth of water of 5 ft. for d and substituting this value in the equation $5^6 - 1,289 \times 5 = 15,625 - 6,445 = 9,180$, which shows that the trial value for d is too great. Trying $d = 4$, $4^6 - 1,289 \times 4 = 4,096 - 5,156 = -1,060$, which shows that this value for d is too small. Trying $d = 4.2$ $(4.2)^6 - 1,289 \times 4.2 = 5,489 - 5,413.8 = 75.2$, which is less than the required quantity.

But trying $d = 4.3$ $(4.3)^6 - 1{,}289 \times 4.3 = 6{,}321.5 - 5{,}542.7 = 778.8$, which is too great. Therefore, taking the mean of 4.2 and 4.3 or 4.25 = 4 ft. 3 in., this value can be verified by calculating the amount of water such a flume will discharge under the given conditions, $p = 4\,d = 4\frac{1}{4} \times 4 = 17$ ft. $A = 2\,d^2 = 2\,(4\frac{1}{4})^2 = 36.125$ sq. ft. $r = \frac{36.125}{17} = 2.125$. Substituting these values in formula **4**, Art. **40**, $v = r\sqrt{\frac{100{,}000 \times s}{6.6\,r + .46}} = 2.125\sqrt{\frac{100{,}000 \times .0016}{6.6 \times 2.125 + .46}} = 7.06$ ft. per sec. Hence, $Q = A\,v = 36.125 \times 7.06 = 255$ cu. ft., which satisfies the conditions of the problem very closely. Ans.

WEIRS

44. A **weir** is an obstruction placed across a stream for the purpose of diverting the water so as to make it flow through the desired channel. This channel may be an opening in the obstruction itself; and it has been found that, when properly constructed and carefully managed, such a weir

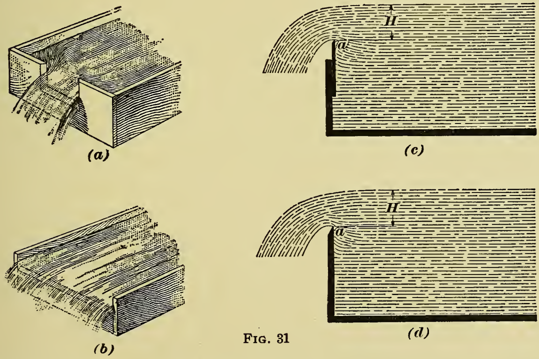


Fig. 31

forms one of the most convenient and accurate devices for measuring the discharge of streams.

A weir with end contractions is shown in Fig. 31 (a). The notch is narrower than the channel through which the water ordinarily flows, thus causing a contraction at the bottom and two sides of the issuing stream.

A weir without end contractions, also called a weir with end contractions suppressed, is shown in Fig. 31 (*b*). In this case, the notch is the full width of the channel leading to it and consequently the stream issuing is contracted at the bottom only.

45. Crest of the Weir.—The edge *a*, Fig. 31 (*c*) and (*d*), is called the crest of the weir; it should be beveled so that the water in passing over it touches only a sharp edge. For very accurate work, both side and bottom edges should be made from thin plates of metal having a sharp inner edge, as shown at *a*, Fig. 31 (*c*); but for ordinary work, the edges of the board in which the notch is cut may be beveled, as shown in (*b*). Frequently, this edge is not made absolutely sharp, but is left flat for about $\frac{1}{8}$ inch, so as to increase the strength of the edge and to decrease the liability of its being damaged. The bottom edge of the notch must be straight and perfectly level; the sides must be at right angles to the bottom. The inside edges of the notch must always be in a plane at right angles to the surface of still water. The head H producing the flow is the vertical distance from the crest of the weir to the surface of the water, as shown in Fig. 31 (*c*) and (*d*); this head must be measured at a point sufficiently back from the crest so that the surface of the water is not affected by the curvature of the stream flowing over the weir.

The distance from the crest of the weir to the bed of the stream should be at least three times the head, and with a weir having end contractions, the distances from the vertical edges to the banks of the stream should each be at least three times the head also. The water must approach the weir with little or no velocity; to accomplish which it is sometimes necessary to provide means, such as baffle boards, for reducing the velocity of approach.

DISCHARGE OF WEIRS

46. When the dimensions of the notch and the head on the crest of a weir are known, the discharge can be computed by means of the following formulas and tables of coefficients,

in which l = length of weir, in feet;
H = measured head, in feet;
v = velocity with which water approaches the weir, in feet per second;
h = head equivalent to velocity with which water approaches the weir, or a head that would produce a velocity equal to v;
c = coefficient of discharge;
Q = actual discharge, in cubic feet.

The actual discharge for weirs with end contractions is given by the formulas:

$$Q = 5.347\,c\,l\,(H + 1.4\,h)^{\frac{3}{2}} \qquad (1)$$

which is used where the water approaches the weir with a velocity equivalent to the height h, and

$$Q = 5.347\,c\,l\,H^{\frac{3}{2}} \qquad (2)$$

where the water has no velocity of approach.

The actual discharge for weirs without end contractions is given by the following formulas:

$$Q = 5.347\,c\,l\,(H + \tfrac{4}{3}\,h)^{\frac{3}{2}} \qquad (3)$$

which applies in cases where the water has a velocity of approach, and

$$Q = 5.347\,c\,l\,H^{\frac{3}{2}} \qquad (4)$$

which applies where the water has no velocity of approach.

47. Velocity of Approach.—By this term is meant the velocity with which the water flows through the channel leading to the weir. This may be obtained by finding, approximately, the amount of water discharged in a given time and the area of the cross-section of the channel leading to the weir. Then the velocity of approach will be equal to the given amount of water divided by the area; or,

A = area of cross-section of channel, in square feet;
v = velocity of approach, in feet per second;
Q = quantity of water, in cubic feet.

Then,
$$v = \frac{Q}{A}$$

Q may be obtained, approximately, by assuming that v is equal to zero and applying the formula for the class of weir

TABLE II

COEFFICIENTS FOR WEIRS WITH END CONTRACTIONS

Effective Head Feet	Length of Weir, in Feet						
	.66	1	2	3	5	10	19
.1	.632	.639	.646	.652	.653	.655	.656
.15	.619	.625	.634	.638	.640	.641	.642
.20	.611	.618	.626	.630	.631	.633	.634
.25	.605	.612	.621	.624	.626	.628	.629
.30	.601	.608	.616	.619	.621	.624	.625
.40	.595	.601	.609	.613	.615	.618	.620
.50	.590	.596	.605	.608	.611	.615	.617
.60	.587	.593	.601	.605	.608	.613	.615
.70		.590	.598	.603	.606	.612	.614
.80			.595	.600	.604	.611	.613
.90			.592	.598	.603	.609	.612
1.00			.590	.595	.601	.608	.611
1.2			.585	.591	.597	.605	.610
1.4			.580	.587	.594	.602	.609
1.6				.582	.591	.600	.607

NOTE.—The head given is the effective head, $H + \frac{4}{3}h$. When the velocity of approach is small, h is neglected.

in question, as given above. Having obtained this quantity Q and from it the value of v, the equivalent head h may be found by the formula

$$h = .01555\ v^2$$

Since v is small with a properly constructed weir, it is usually neglected unless great accuracy is required.

48. Table II gives the values of the coefficients of discharge c for weirs with end contractions and different values of H and l. In this table, the head given is the effective head $H + \frac{4}{3} h$. When the velocity of approach is small, h is neglected and the head becomes simply H, but this change will not affect the coefficients in the table.

Table III gives the values of c for weirs without end contractions. Weirs with end contractions are more often used

TABLE III

COEFFICIENTS FOR WEIRS WITHOUT END CONTRACTIONS

Effective Head Feet	Length of Weir, in Feet						
	19	10	7	5	4	3	2
.10	.657	.658	.658	.659			
.15	.643	.644	.645	.645	.647	.649	.652
.20	.635	.637	.637	.638	.641	.642	.645
.25	.630	.632	.633	.634	.636	.638	.641
.30	.626	.628	.629	.631	.633	.636	.639
.40	.621	.623	.625	.628	.630	.633	.636
.50	.619	.621	.624	.627	.630	.633	.637
.60	.618	.620	.623	.627	.630	.634	.638
.70	.618	.620	.624	.628	.631	.635	.640
.80	.618	.621	.625	.629	.633	.637	.643
.90	.619	.622	.627	.631	.635	.639	.645
1.00	.619	.624	.628	.633	.637	.641	.648
1.2	.620	.626	.632	.636	.641	.646	
1.4	.622	.629	.634	.640	.644		
1.6	.623	.631	.637	.642	.647		

NOTE.—The head given is the effective head $H + \frac{4}{3} h$ When the velocity of approach is small, h may be neglected.

and are to be recommended in most cases. Values of c corresponding to values of H and l between those given in the tables can be found by interpolating or taking an average between the desired figures, assuming that the variation is uniform between the values given. In Table III, the head

given is the effective head $H + \frac{4}{3}\ h$, which, when h is neglected, becomes simply H. This does not affect the value of the coefficient in the table.

TABLE IV

CUBIC FEET DISCHARGED PER MINUTE FOR EACH INCH IN LENGTH OF WEIR FOR DEPTHS FROM 1-8 INCH TO 25 INCHES

Inches		1/8	1/4	3/8	1/2	5/8	3/4	7/8
0		.01	.05	.09	.14	.20	.26	.33
1	.40	.47	.55	.65	.74	.83	.93	1.03
2	1.14	1.24	1.36	1.47	1.59	1.71	1.83	1.96
3	2.09	2.23	2.36	2.50	2.63	2.78	2.92	3.07
4	3.22	3.37	3.52	3.68	3.83	3.99	4.16	4.32
5	4.50	4.67	4.84	5.01	5.18	5.36	5.54	5.72
6	5.90	6.09	6.28	6.47	6.65	6.85	7.05	7.25
7	7.44	7.64	7.84	8.05	8.25	8.45	8.66	8.86
8	9.10	9.31	9.52	9.74	9.96	10.18	10.40	10.62
9	10.86	11.08	11.31	11.54	11.77	12.00	12.23	12.47
10	12.71	13.95	13.19	13.43	13.67	13.93	14.16	14.42
11	14.67	14.92	15.18	15.43	15.67	15.96	16.20	16.46
12	16.73	16.99	17.26	17.52	17.78	18.05	18.32	18.58
13	18.87	19.14	19.42	19.69	19.97	20.24	20.52	20.80
14	21.09	21.37	21.65	21.94	22.22	22.51	22.79	23.08
15	23.38	23.67	23.97	24.26	24.56	24.86	25.16	25.46
16	25.76	26.06	26.36	26.66	26.97	27.27	27.58	27.89
17	28.20	28.51	28.82	29.14	29.45	29.76	30.08	30.39
18	30.70	31.02	31.34	31.66	31.98	32.31	32.63	32.96
19	33.29	33.61	33.94	34.27	34.60	34.94	35.27	35.60
20	35.94	36.27	36.60	36.94	37.28	37.62	37.96	38.31
21	38.65	39.00	39.34	39.69	40.04	40.39	40.73	41.09
22	41.43	41.78	42.13	42.49	42.84	43.20	43.56	43.92
23	44.28	44.64	45.00	45.38	45.71	46.08	46.43	46.81
24	47.18	47.55	47.91	48.28	48.65	49.02	49.39	49.76

49. Table IV gives the quantity of water, in cubic feet per minute, flowing over a weir for each $\frac{1}{8}$ inch of effective

head from $\frac{1}{8}$ inch to 25 inches, for each inch of length of weir. To obtain the quantity of water for any given case, multiply the quantity given in Table IV, corresponding to the given effective head, by the width of the weir in inches.

50. To illustrate the use of Table IV, find the volume of water discharged per minute over a weir 30 inches in length with a head of 3 inches. The quantity of water corresponding to an effective head of 3 inches, is 2.09 cubic feet; then multiplying this by the given length of weir (30 inches), we have $2.09 \times 30 = 62.7$ cubic feet per minute. When the head is expressed in inches and fraction of an inch, the whole number of inches is first sought in the left-hand column, and the required quantity of water is then found on the same line, in the column indicated by the given fraction of an inch. Thus, in the above example, if the effective head had been $3\frac{1}{2}$ inches instead of 3 inches, the quantity of water flowing over the weir would have been $2.63 \times 30 = 78.9$ cubic feet per minute.

MINE DRAINAGE

Serial 854 Edition 1

THE HANDLING OF MINE WATER

SURFACE DRAINAGE

1. Draining, or **unwatering,** a mine means the removal of the water that accumulates in it. It is a subject that usually increases in importance as the mine is developed, since many mines that are dry near the outcrop become more and more watery as they increase in depth. The importance of the subject is shown by the fact that, in many cases, the weight of water pumped out of a mine is many times the weight of material hoisted—30 tons of water being hoisted in some instances for every ton of coal mined. The cost of the material produced is thus greatly increased, as the pumping charges are usually a dead loss.

2. Keeping Surface Water From the Mine.—In order to keep as much water as possible out of mine workings, precautions should be taken at the surface to keep it from collecting above the workings or along the outcrop. The outcrop of a soft deposit, such as coal, is often distinguished by a depression in the surface, which forms a natural sink in which the water from the surrounding area collects. This collection of water may be prevented by digging a ditch along the outcrop to carry off the water.

It is impossible to absolutely prevent percolation from the surface, as part of the rainfall is always absorbed and eventually finds its way into the mine. If water percolates into mines from the bed of a stream, it is sometimes possible

and advantageous to turn the course of the stream, particularly if it flows over a mine where the extraction of the deposit is likely to disturb the bed of the stream when roof falls occur. Where the water from a stream enters a mine, and the stream cannot be turned from its course, it may, if not too large, be carried over the affected area in wooden flumes.

3. Flow of Water Into Mines.—The water that finds its way into a mine may come from the surface or from water-bearing strata overlying or underlying the workings. It may enter the mine by percolating through porous rocks, through the joints or fissures formed in the strata, or may seep in through the bedding planes of the strata, and the flow into a mine is often increased by a fall of roof and by long-continued and heavy rains. When rain falls on the surface of the earth, part of the water runs off and part soaks into the soil and sinks until arrested by an impervious stratum. The amount of water from rainfalls that soaks into the ground depends on the contour of the surface and the nature of the soil. If there are no depressions, and the surface drainage is good, most of the water that falls on the surface will run off; but when depressions exist in which the water can collect, as in ponds or swamps, gradual percolation will continue over the wet area and the water will find its way into underground workings, unless the overlying strata are impervious to water, or crevices lead it from the workings. The amount of water that enters the mine through fissures and crevices in the strata depends on the porosity of the strata and the size of the crevices through which it passes; crevices permit a large inflow from the surface, if they occur in river or lake bottoms, or if they pass through water-bearing strata. Faults crossing many strata may become channels through which water enters a mine. Mineral veins that are formed in fissures are generally water bearing, the water following along the vein walls in most instances, but sometimes in the vein matter if this has oxidized.

When the strata are of such a nature that underground waters can circulate through the crevices, the water may dissolve the

rock and form cavities in which large bodies of water collect, at times under great pressure. In the development of a mine, the strata left between the excavation and these cavities may not be sufficiently strong to oppose the pressure, in which case the breaking of the strata will cause an inrush of water into the mine, and may cause loss of life and damage to the mine. Where pot holes occur in the measures, or where the mine workings are under an old river bed, it is customary to systematically test the thickness of the strata above the workings by bore holes.

4. **Variation in the Amount of Water.**—The amount of water entering a mine usually increases as the excavation is extended, but not always in proportion to the extent of the excavation, since water does not enter in the same quantity in all places. Where there are several coal beds being worked, the deepest bed frequently contains the least water; exceptions to this rule are sometimes found in the anthracite fields of Pennsylvania, where the strata have been folded.

The passage of the water through the soil and rock strata is retarded by the effect of capillary attraction, which causes the strata to absorb and hold the water in the same manner as a sponge. Owing to this, the strata give off little or no water until saturated, and the effect of an increase of surface water is not felt farther down for a long period. This is the reason why the effect of a heavy rainfall is not generally felt until some time later, and in deep mines it may be wholly unnoticed. The amount of water entering a mine also varies greatly in different seasons of the year, the maximum amount being usually in the spring. Hence, the appliances for unwatering the mine must be based on the maximum amount and not on the average.

In working inclined deposits to the rise, the mistake is often made of driving so near to the outcrop that caves occur. This is bad practice, as it not only injures surface property, but allows surface water to drain into the mines whenever it rains or snow melts. After hard or continued rains, the surface water entering such caves has frequently flooded the mine.

UNDERGROUND DRAINAGE

5. Water Level.—The point reached below the outcrop, where the surface water does not flow away naturally but must be got rid of by artificial means, is termed **water level.** Geologists sometimes term this *the level of underground waters*.

The method of draining a mine depends largely on whether the deposit is flat or inclined, and whether the mining is being done above or below water level. Above water level, pumping is usually unnecessary, except for local depressions or swamps, and attention is given chiefly to the location and preparation of ditches to carry off the water and to keep it out of the way of the workmen and off the haulage roads. Below water level, a sump must be provided, to which the water is drained and from which it is raised to the surface, or to the water level.

FLAT DEPOSITS ABOVE WATER LEVEL

6. Adit Drainage.—An **adit** is a nearly horizontal passage from the surface, with just sufficient slope to insure drainage, and by which a mine is unwatered. The term adit, therefore, includes both a drift in the deposit or a tunnel in rock across the measures. A **flat deposit** is a level or slightly inclined deposit. Whenever such a deposit can be worked through adit levels, it is customary to locate the mine opening at the lowest available point on the property where the deposit outcrops above water level and then to drive the main roads at a slight inclination so as to obtain a fall toward the mine opening that will insure natural drainage for the greatest possible area. If these adits are to be used as haulage roads, they are provided with ditches excavated either at one side or underneath the track. Water will run in smooth ditches that have a uniform grade of 2 inches in 100 feet; but it is customary to give them a steeper grade than this, because dirt and rubbish will accumulate in them, especially on haulageways. The floors of bedded deposits seldom have uniform inclinations, but rise and fall in places; and it is well to give the ditches uniform grades, irrespective

of the changes of the floor, if possible; but as this may require considerable cutting of bottom rock the drainage is often allowed to follow the natural channel, to avoid cutting deep ditches in the entry.

7. **Cross-Entry Drainage.**—It is also customary, wherever possible, to drive the cross-entries to the rise, at such an angle with the main haulageways as will afford natural drainage. If necessary, ditches are also provided along these cross-entries so that any water that enters this part of the mine may drain toward the main entry or adit. If there are natural rises or sinks in the floor in which water accumulates, ditches may be deepened if no other economical method can be suggested to drain such areas.

8. **Swamp Drainage.**—Swamps in mines are not generally deep or wide and, like swamps found at the surface, have high and low places, the latter being the water channels. When the miner approaches a swamp, the floor commences to dip slightly and water comes into the working. When only a small quantity of water accumulates, it is bailed into a water car and hauled out of the mine on the commencement of each shift. If more than three water cars are required before the place is in a satisfactory condition for the miner to work, this method of drainage is too slow and expensive; and if the swamp is a foot or more deep, a hand pump, an electric pump, or a compressed-air pump should be used in its place. Such pumps are connected with a delivery pipe that leads into the nearest ditch and will ordinarily drain a good-sized swamp. As soon as the swamp has been passed through and the floor of the deposit assumes its regular inclination, no further pumping will be necessary since the water that was in the swamp channels will, as a rule, flow off in its natural channel and not accumulate and overflow into the mine.

9. **Contour Drainage Map.**—It is an excellent plan, and one now often followed in coal mines where swamps are found, to take their levels and place them on the mine map, and to make a **contour map** of the floor of the bed, as shown in Fig. 1.

The general contour of the affected district being thus ascertained, it will be possible, in most instances, to cut one

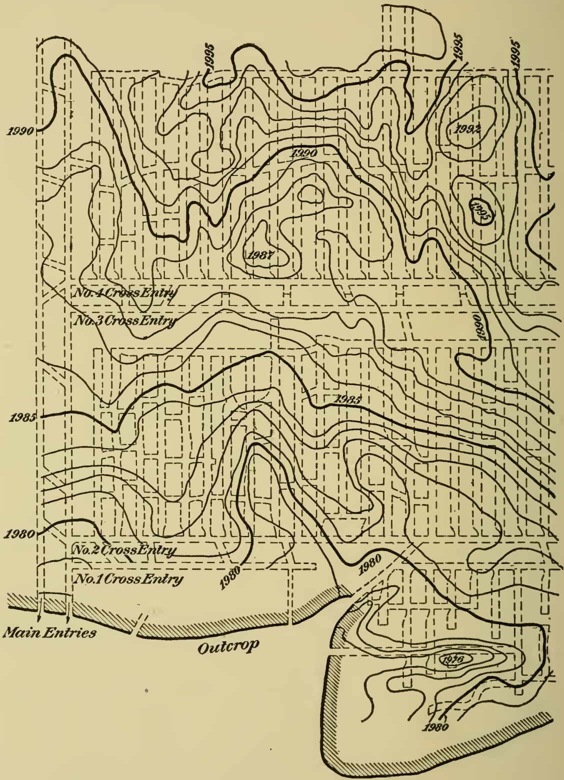


FIG. 1

ditch that will drain the entire troublesome area. A ditch here and there, cutting across local anticlinals or high places, may bring water from the different drainage areas of the

mine into a main ditch or natural waterway. If the conditions permit, this waterway may be located near, and parallel to, main haulageways, where it will be accessible and will be part of a scheme working in harmony with future developments. A map of this character permits a systematic drainage system to be laid out, and the use of shorter drainage ditches than would otherwise be obtained.

10. Drainage of Temporarily Abandoned Mine Workings.—It is customary in some systems of mining bedded deposits, to leave a certain percentage of the mineral as pillars to support the roof, the intention in such cases, being to recover these pillars after the boundary line of the property has been reached. Such temporarily abandoned portions of a mine are likely to have roof falls through which water will enter, and accumulate until it overflows into the active mine workings. If any inconvenience is anticipated from such areas, they should be thoroughly ditched, if the floor is of such a nature as to permit ditching; if not, dams must be constructed to retain the water so that it can be drawn off and led into proper channels by means of a siphon or pump.

11. Drainage of Robbed Areas.—Whenever the mining has reached the boundary of the property and before robbing is commenced, a deep ditch should be made on the dip side of the first panel robbed, to catch the water, which will accumulate in ever-increasing quantity as the area of crushed roof is widened. This ditch should connect with the main drainage ditch, so that the water may be carried away by gravity as much as possible. As the robbing will cause the roof to fall and probably fill this ditch, it will be necessary to construct a new ditch for the next lower panel as that panel is robbed. In flat-bedded workings with a regular dip, such ditches should be made on cross-entries and be completed before robbing the panel is commenced.

It is sometimes possible to drive from the lowest point of the outcrop, near the robbed portion of the mine, a tunnel that will drain off the water and prevent its backing into the

workings and traveling roads; or possibly a cross-cut tunnel may be made to tap accumulated water. It may be possible that dams, siphons, or drain pipes attached to dams will afford the desired relief; if not, pumps must be used.

In temporarily or permanently abandoned workings, the mine maps showing the contours of an irregular mine floor will be especially valuable as data for locating drainage tunnels and ditches. Experience has shown that, where nearly flat mineral deposits outcrop, the floor often bends upwards similar to the rim of a plate, and that this requires a ditch to be deeper at the outcrop than in the mine in order to obtain proper drainage. In case the floor of the deposit is fireclay, or hard pan, the action of air and water will require the ditches to be cleaned regularly if on traveling roads; but since this is not possible in robbed workings, it follows that the ditches in these places should be wide and deep, so that the water will find a passage between the broken rocks that fall into them.

FLAT DEPOSITS BELOW WATER LEVEL

12. Sumps.—When comparatively flat deposits are worked below water level, the haulageways are usually made the drainage levels and are constructed with ditches that lead to a common catch basin called the **sump.** Sumps are usually excavated near the shaft or incline used for hoisting, so that they will be near the column-pipe that passes through these openings, and so that the pump suction pipe will not be too long. If there are no workings below the pump level, the sump may be made directly under the shaft, otherwise it is placed to one side of the shaft, sometimes in the deposit and sometimes in rock, according to the condition of the strata.

Where the water comes into a mine at some distance from the pump, it may be necessary to provide a local sump and to use an auxiliary pump to send the water from this point to the main sump; or it may be cheaper to unwater this section through a bore hole from the surface, provided that the depth is not too great, or through a shaft sunk for this purpose.

For draining water into sumps numerous methods are employed besides ditches. If the water accumulates some distance from the rise of the sump, it is generally advisable to make an auxiliary sump in that locality and pipe the water to the main sump, by this means keeping it out of the haulageways and keeping them dry. When water accumulates in small quantities on levels above the sump, it may be conducted to the main pump sump by pipes. If, however, the water is in large quantities on the upper levels, it should not be allowed to go to the bottom of the mine, but should be caught in auxiliary sumps and pumped from them to the water level, or to the surface. This may require several auxiliary sumps on the upper levels, but if the quantity of water is large they will soon pay for their construction by the lower cost of pumping from the higher levels.

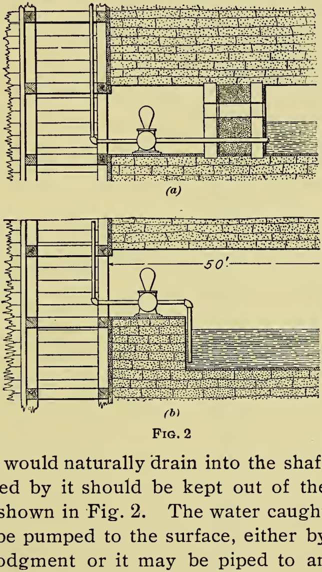


Fig. 2

13. Shaft Lodgment.—In the case of shaft mines, as much as possible of the water that would naturally drain into the shaft from wet strata penetrated by it should be kept out of the shaft by **lodgments**, as shown in Fig. 2. The water caught in these lodgments may be pumped to the surface, either by a pump placed at the lodgment or it may be piped to an auxiliary sump located below the lodgment. Where several flat deposits are worked from the same shaft, the water from each deposit should, when possible, be caught in a sump placed in the rock at the level of the deposit and not allowed to drain to the bottom of the shaft. Fig. 3 shows such an

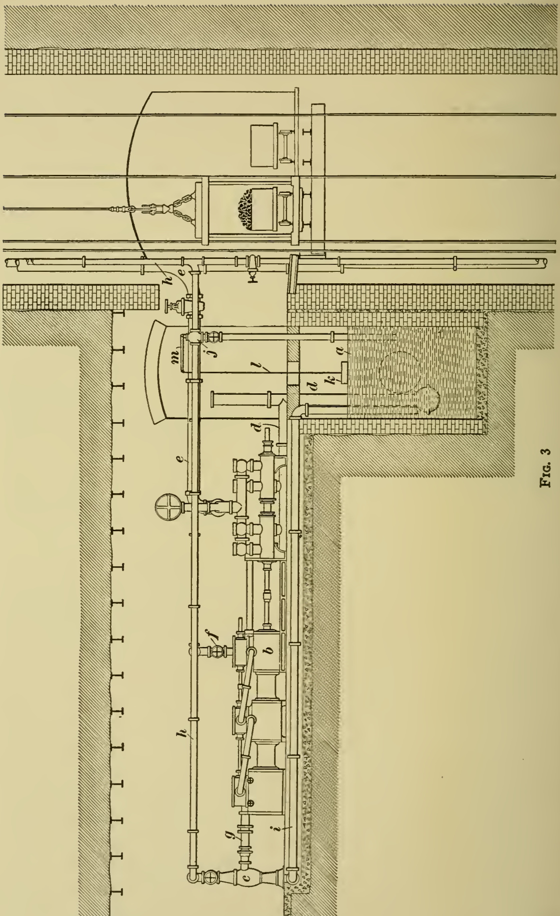


FIG. 3

auxiliary sump *a* placed at the mine level, into which water is drained either from a lodgment or from a level above, and from which it is pumped by a triple-expansion pump *b* connected with a condenser *c*. The pump draws its water from the sump through the pipe *d* and discharges it through the column-pipe *e*. The steam for the pump comes from the surface and is admitted to the high-pressure steam cylinder by the valve *f* and escapes from the low-pressure steam cylinder through the exhaust pipe *g* into the condenser *c*. The water for the condenser comes from the lodgment, or level above, through the pipe *h* and, passing through the condenser, flows through the pipe *i* into the sump. The pipe *h* is equipped with a valve *j* that regulates the quantity of water flowing into the sump, without cutting off the supply needed for the condenser, by means of a float *k*, rod *l*, and lever *m* attached to the valve stem. As the float falls, the lever opens the valve and permits water to flow into the sump; as the float rises, the lever closes the valve, thus cutting off the flow.

EXAMPLE 1.—Suppose that a mine is 600 feet deep, what power will be saved if 1,000 cubic feet of water is pumped to an adit 100 feet below the shaft head rather than to the shaft head?

SOLUTION.—The power required to lift the 1,000 cu. ft. of water 600 ft. in 1 minute is, $\frac{1,000 \times 62.5 \times 600}{33,000} = 1,136.36$ H. P. The power required to lift the same amount of water to the adit, or 500 ft., in the same time is, $\frac{1,000 \times 62.5 \times 500}{33,000} = 946.97$ H. P. The saving, without considering the usual 20 per cent. additional power for friction, will be, $1,136.36 - 946.97 = 189.39$ H. P. Ans.

EXAMPLE 2.—Suppose that in example 1 all the water came from near the surface and could be caught in a sump at a level 200 feet below the surface; what power would be saved by so doing, and not allowing the water to go to the bottom of the shaft?

SOLUTION.—In example 1, it was found that 1,136.36 H. P. is required to pump 1,000 cu. ft. of water from a depth of 600 ft. in 1 minute. The power that would be required to pump the same amount of water in the same time from the 200-ft. level is,

$$\frac{1,000 \times 62.5 \times 200}{33,000} = 378.78 \text{ H. P.}$$

The saving will be $1,136.36 - 378.78 = 757.58$ H. P. Ans.

INCLINED DEPOSITS ABOVE WATER LEVEL

14. Adit Drainage.—Adits in inclined deposits are suitable for draining all the deposits above them. Drainage ditches should be placed either on the side or beneath the roadway, and should have a uniform grade of not less than 4 inches, or more than 8 inches, in 100 feet, the grade being governed by that given the roadway. The ditch should, in most instances, be on the foot-wall side of the deposit as shown in Fig. 4, as then it will not be necessary to break the hanging wall, and water will not be so apt to drop into the roadway and keep that wet. Further, whatever water may trickle or run down the hanging wall can be led across the adit to the ditch side and be drained off. When the deposit is worked below the adit level, if the ditch is made on the foot-wall side of the deposit, most of the water will drain off through the adit and not be troublesome in the lower workings.

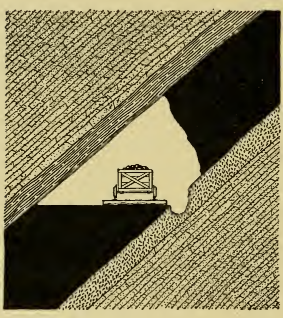


Fig. 4

If the deposit is wide and it is not necessary to break either the hanging wall, or foot-wall, for passage room, the ditch should be placed on the foot-wall side. If the greater part of the water comes from the hanging-wall side, it may be necessary to place ditches on each side of the adit, but the main ditch should be on the foot-wall side, with the ditch on the hanging-wall side answering as a gutter or leader to the main ditch. It may not be necessary to carry the ditch on the hanging-wall side the entire length of the adit, since extremely wet places are local; but where they occur the gutter leading to the main ditch will be found a great convenience, and very economical where there are lower workings.

15. In some instances, the ditch in an adit is made beneath the track, as in Fig. 5. In wide deposits, this is not objectionable if, for some reason, it is not desirable to work close to the foot-wall, but the chances for the water that runs in the ditch going to the lower levels are much increased when ditches are so arranged, unless the deposit is tight or practically impervious. In an adit of small area a center ditch may be necessary on account of weak walls or close timbering. When conditions are favorable for side ditches, it is bad and expensive practice to use a center ditch, since the cross-ties must be planked over and this covering kept in good order. Another disadvantage is that ditches beneath a track cannot be regularly cleaned without considerable extra labor and expense for the removal and replacement of the plank covering.

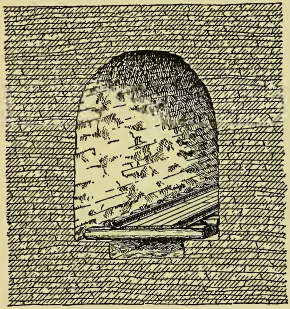


Fig. 5

16. Drainage Tunnels. **Drainage tunnels** are tunnels driven to tap a given mine or mining district below the natural water level of the district. Such tunnels have been driven 1,700 feet below the shaft mouth and many miles long. The Sutro tunnel, in Nevada, was excavated for the purpose of unwatering the mines on the Comstock lode. It was driven with great difficulty because of the extreme heat of the rocks and water, and the swelling ground, which broke the strongest timbers, and because 45.5 per cent. of the entire length required timbering. The water in this tunnel is carried in a ditch cut in the tunnel floor; it amounts to 12,000 tons daily, and has a temperature of 123° F. when it leaves the tunnel mouth. To pump this water to the surface, before the tunnel was constructed, cost $3,000 per day.

Occasionally, the owners of several mines club together and build drainage tunnels, or a corporation is formed for the purpose of tunneling to unwater several mines, such as the Aspen Tunnel Company, at Aspen, and the Wooster Tunnel, at Creede, Colorado. These tunnels may also be used as haulageways, while the companies become owners of any veins they discover in driving the tunnel.

Tunnels for drainage purposes, to be of much practical value, must be driven at a considerable depth below the mouth of the mine. This is expensive work in barren ground, and all advantages to be derived from their excavation should be well considered. It is not advisable to drive a drainage tunnel to meet a mineral deposit that has not been previously prospected to a depth equal to that of the proposed tunnel level, if the value of the deposit is to defray the cost of driving, for there is no surety that the mineral will continue to that depth. Experience has taught that cross-cut tunnels are not to be driven haphazard, and that their usefulness should be determined from known rather than supposed data. There are a number of instances on record where cross-cut tunnels were driven at great expense to cut mineral deposits which petered out or were faulted before the tunnel depth was reached.

17. The **Jeddo tunnel**, in the Black Creek anthracite basin of Northeastern Pennsylvania, is about 5 miles long, extending from Black Creek under the intervening hills to Butler Valley. Black Creek Valley is at a considerably higher altitude than Butler Valley, hence it was possible to tunnel under the coal beds and drain the mines above and below the Black Creek level. The mines in Black Creek Valley, previous to the construction of the tunnel, suffered from the waters of Black Creek draining into them and several times some of them had been flooded. This tunnel, however, drained the area most affected and helped the other area, thus making large quantities of first-class coal available for market. The line of the tunnel having been mapped out, two slopes were sunk to give five headings to the tunnel and

so expedite the work. The tunnel was 7 feet by 11 feet in sectional area and, by the use of compressed-air drills, was driven at a rapid rate, 308 feet being driven in one heading and $301\frac{1}{2}$ feet in another during May, 1894.

INCLINED DEPOSITS BELOW WATER LEVEL

18. Sumps are placed in the mine as was described in Art. **12.** Sumps on upper levels should be dug in the foot-wall and be cemented to make them water-tight in order that no water may run back to the next lower pumping station. If the sump is to act merely as a catch basin for the pump below, a large wooden tank may answer every purpose; but where the sump is located in the deposit, or in seamy country rock, and not made water-tight, leakage will occur and the water will have to be raised from a lower level.

19. Ditches on Levels.—The main drainage ditches in inclined deposits are on the levels that are driven right and left from the pump shaft, or slope. The position of the ditch on the level depends on the position of the level with respect to the deposit. These levels are driven in the deposit wherever the conditions will permit; and when that is not possible, they are driven partly in the deposit and partly in the country rock, or sometimes entirely in the country rock. They are given a uniform grade varying from 2 inches to 8 inches in 100 feet; the latter, however, is excessive for most cases. Fig. 6 shows a level driven entirely in the deposit, with a ditch on the foot-wall side, the mineral in this case being firm enough to stand without timber, besides carrying little water.

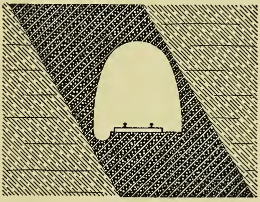


FIG. 6

Fig. 7 shows a level driven entirely in the deposit, which must be supported overhead by timbers. In this case, the

ditch is on the foot-wall side. Fig. 8 shows a level driven partly in firm vein rock and partly in rather weak country rock, the ditch, in this case, being placed on the foot-wall. There are numerous other situations in which levels may be driven, but it is usually advisable to place the ditch on the foot-wall side.

In a situation similar to that illustrated in Fig. 9, where

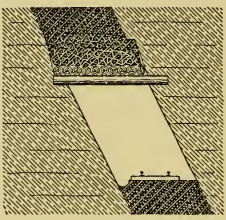


Fig. 7

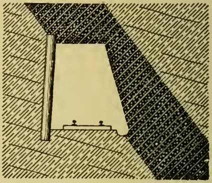


Fig. 8

the ground is weak on all sides and requires timber sets for its support, the ditch is necessarily placed below the sills; but in such a case as shown in Fig. 10, where only the

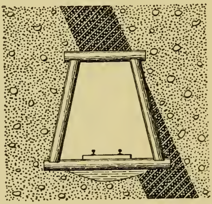


Fig. 9

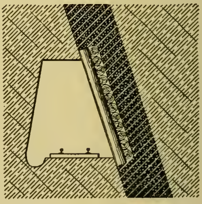


Fig. 10

deposit is weak, the ditch is probably located best away from the bed, water being drained to it by local gutters. If the roof is water bearing and the deposit is not, the ditch should generally be placed on the hanging-wall side, thus making an exception to the regular rule.

DRAINAGE OF WORKING PLACES

20. Room Drainage.—In working flat seams, it often happens that the drainage, though slight, is toward the working face instead of toward the mouth of the room, where the water would be discharged into the ditch along the entry. When water drains toward the mouth of the room, little care on the part of the miner is required; but when the water drains toward the face, recourse must be had to the water car and bailing, to remove the water from the face of the rooms. If there is an excessive amount of water, which would delay work at the face, it is sometimes advantageous, or even necessary, to excavate a small sump at the lowest point of the face by placing a light shot in the bottom.

In working inclined seams, rooms are seldom driven to the dip of the seam, and hence little trouble is experienced in the drainage of the working face. Care, however, is required in all inclined workings to prevent, as far as possible, the water in one level from finding its way into the workings below. To accomplish this, a continuous chain pillar is maintained on the lower side of each level or gangway, and careful measurements are taken in each room to avoid driving the rooms from below up through this pillar; or, sometimes, to prevent any possibility of the rooms driven up from a lower level breaking through the chain pillar, a cut-off room is driven parallel to, and just below, each level. The entry ditch in each level is carried on the side of the roadway up the pitch, that is, on the foot-wall side, to prevent the water, as far as possible, from seeping under the pillar dividing this level from the workings below, as would naturally be the case if the ditch were carried on the opposite side of the entry.

21. Drainage in Stope Mining.—In stope mining, continuous pillars with ditches are not always left to carry the water away from the miner working below. Therefore, where there is much water to contend with, at certain

intervals winzes are sunk from one level to another, or raises are driven from one level to a level above, in order to drain the water from the stope. If the level is one on which there is a pump, a chain pillar should be left below the level and arrangements made to carry the water over any hole made through this pillar from below. If there is not a pump on the level, all water should be led as directly as possible to a lower level away from working stopes, where it would cause inconvenience to the men. In underhand stoping, the water follows the stopes, often making ore and tools wet; but in overhand stoping, the men in the upper stope are more inconvenienced by water than those on lower stopes.

TAPPING AND DRAINING ABANDONED WORKINGS

22. When exploitation has reached the boundary line of a property and the mine has been robbed back and aban-

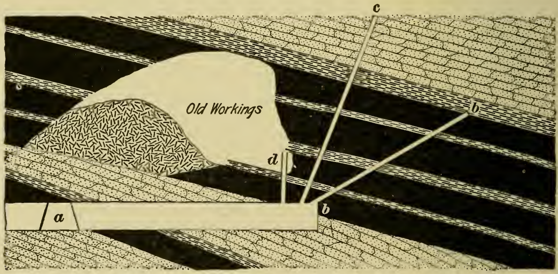


FIG. 11

doned, water is likely to accumulate until the mine has filled. If other mining operations are approaching this abandoned property, all entries should be carefully driven narrow and a bore hole pushed at least 20 feet in advance of the face, and similar bore holes to flank each side. Bore holes 20 feet long are not considered by some to be a sufficient safeguard in a thick seam or on steep dips, but this must necessarily depend on the depth of the water and the strength of the coal.

By disregarding such simple precautions, and because records of old mine excavations have not been kept or examined, a number of accidents that have caused loss of life, as well as serious damage to mining property, have resulted. Some state mine laws require that duplicate surveys be made before a mine is abandoned and these surveys must agree and be accurately plotted on a map. A certified copy of this map is then filed with the mine inspector of that particular district.

Fig. 11 shows the risk run in approaching old workings known to exist but not surveyed and mapped. The gangway *a* was being worked in coal, and it was thought advisable to cross-cut to reach another bed that had been worked and in which at this depth there would be a head of 150 feet of water. The diamond-drill hole *b* was drilled from the cross-cut heading at a 33° pitch, but no water was struck. The hole *c* was next drilled at a 70° pitch, so as to cut the seam at nearly right angles; this hole gave some water, but no absolute position of the old workings, and was as unsatisfactory as the first. The hole *d* was next drilled vertically about 3 feet back of the hole *c*, so as to reach the coal; this struck into old workings, but did not show water until within 2 feet of them.

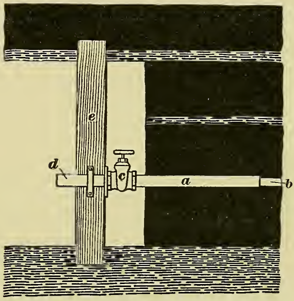


FIG. 12

23. Draining Off Water.—If the bore hole taps a body of water in an abandoned mine, a larger hole is drilled into the face and a pipe *a* is inserted into the face 4 or 5 feet, as shown in Fig. 12. Through this pipe, a hole *b* of smaller diameter is bored until the water is reached. A valve *c*, with an extension *d*, is placed on the pipe and fastened to a heavy prop *e* to prevent the water from blowing out the pipe when

the valve is turned off. The object of this arrangement is to drain off the accumulated water gradually and not let it flow in such quantities as to flood the mine. This arrangement has also been adopted to prevent the water in an abandoned mine rising to a height that would endanger the barrier pillar.

24. Tapping a Body of Water From Below.—In the following case, a cross-cut tunnel was driven to tap a body of water above the tunnel. In driving toward the water, flanking holes and horizontal holes were driven ahead of the work. When the first hole tapped the old workings, 12.5 feet of strata remained between the two excavations. Twelve diamond-drill holes 10 inches from each other were then run into the old works, but on account of their small size and the enormous pressure of the water, these holes were quickly blocked with sediment so that this plan had to be abandoned.

Long wooden plugs were then driven into the holes and each plug pierced by an auger hole, which was charged with dynamite and fired with the expectation that the shots would break down the barrier. The result was a surprise, as the holes simply acted like so many cannon, only a part of the plug being broken. Seventy-five pounds of dynamite was next placed in holes driven slanting to a depth of about 7 feet, the expectation being that the charge would burst through the barrier and discharge the water. When the charge was fired there was at first a great rush of water, which, however, stopped immediately, and then not as much water as would flow from one drill hole escaped. It was evident from this that the heavy pressure of water had not only counteracted the force of the dynamite, but forced the sediment that had accumulated in the old workings into the crevices formed by the explosion and stopped them up. The coal was so shattered by the last explosion that it was not deemed advisable for the men to work at this place. A second tunnel was then driven parallel to the first one, and a vertical rise 4 feet square was driven up 6 feet when a dividing slate was reached; then

it was narrowed to 3 feet square through the 10 inches of slate, and again narrowed to 2 feet square in the coal bench and carried to within 2 feet of the old workings. A prop, 14 inches in diameter, having on top a 14-inch square iron box was so set in this shaft that the box came close to the roof of the shaft. The box was partly filled with dynamite, which was fired by electricity. To prevent the prop from stopping the flow of water, it was necessary to bore a hole in it with an auger, and in this hole a dynamite cartridge was fired immediately after the charge exploded in the pan, thus breaking down the prop and letting out the water.

25. Barrier Pillars.—The laws of some states require a pillar of coal to be left in each bed of coal worked, along the line of adjoining properties, of such width, that, taken in connection with the pillar to be left by the adjacent property owner, it will form a sufficient barrier for the safety of the employes of mines on either property in case one should be abandoned and allowed to fill with water. These pillars are known as **barrier pillars.** The width of such pillars is determined by the engineers of the adjoining property owners and the mine inspector in whose district the properties are located.

An arbitrary rule for the width of barrier pillars, adopted by a number of coal companies and by the State Mine Inspectors of Eastern Pennsylvania, is as follows:

Rule.—*Multiply the thickness of the deposit, in feet, by 1 per cent. of the depth below drainage level, and add to this five times the thickness of the bed.*

Thus, for a bed of coal 6 feet thick and 400 feet below drainage level, the barrier pillar will, according to this rule, be $(6 \times 400 \times .01) + (6 \times 5) = 54$ feet wide.

The bituminous mine law of Pennsylvania requires a thickness of 1 foot of pillar for each $1\frac{1}{4}$ feet of water head, if, in the judgment of the engineer of the property and of the district mine inspector, this thickness is necessary for the safety of the persons working in the mine.

MINE DAMS

26. Use of Mine Dams.—**Dams** are built for the following purposes: to confine water to certain parts of a mine in order to reduce the flooded area and the pumping charges; to prevent the pumps being flooded when the inflow of water to the mine is excessive in wet weather; for the purpose of flooding the whole or a part of a mine to extinguish a mine fire; and to keep back deleterious gases given off in old mine workings. They are made of wood, brick, stone, or concrete and should be provided with drain pipes near the floor, a manway near the center of the dam, and an air escape for air or gases close to the roof. The drain pipes and air vents are furnished with valves or cocks to regulate the flow.

Dams in mines necessarily differ from those constructed above ground, since nearly every square foot of the surface of a mine dam exposed to the water is subjected to practically the same pressure. The principal requirements of a mine dam are that it shall be water-tight and capable of resisting the pressure of a given head of water. Before the dam is planned, a full understanding of the attending conditions must be had; as, for example, the surroundings in which it will be located and what the pressure against it will be. These data are necessary in order to calculate the required strength of the dam and to determine its form and thickness and the material for its construction.

27. Location of Dams.—The site chosen for a mine dam should be such that the junction between the sides of the excavation and the material of the dam can be made water-tight, since a small leak may increase to such proportions as to endanger the entire work. A dam should have solid-rock sides, top, and bottom wherever possible; if this is not possible, rock roof and bottom are the next most desirable; but in case the deposit is on a pitch, it may be necessary to place the dam partly in the deposit and partly in rock. The sides of the excavation against which the dam abuts will need more care if they are in the deposit than if

in solid rock, particularly if the width of the dam is to be greater than its height.

Dams should be located in an accessible place, where they may be easily inspected and where subsequent mining will not disturb their stability or that of the walls to which they are tied; they should be built in a narrow place, if such is available.

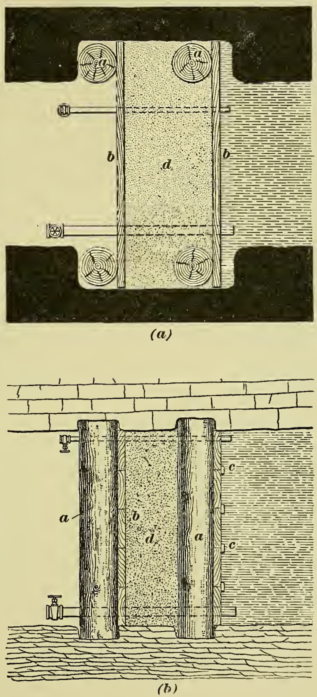


FIG. 13

28. Water Pressure on Dams.—The pressure against a dam is equal to the rectangular area of the face of the dam against which the water presses multiplied by the mean head of water, in feet, and by 62.5 pounds, the weight of a cubic foot of water, when the area is expressed in square feet; or by .434 pound, the weight of 12 cubic inches of water, when the area is expressed in square inches. The mean head used is the vertical distance from the center of the dam to the surface of the water. Thus, if a mine is flooded and the vertical depth of the water is 100 feet, the pressure per square foot at the bottom is equal to the weight of 1 cubic foot of water multiplied by the depth, in feet, or 100. Hence, $62.5 \times 100 = 6{,}250$ pounds per square foot. At a point halfway down, the water will press against the sides with a

pressure equal to $\frac{100}{2} \times 62.5$ pounds $= 3{,}125$ pounds per square foot.

Example.—What pressure must a mine dam that is built across a gangway 10 feet wide and 6 feet high withstand, when the water in the mine can rise to a point 203 feet vertically above the floor of the gangway?

Solution.—The area of the face of the dam is $10 \times 6 = 60$ sq. ft. and the mean head is $203 - \frac{6}{2} = 200$; therefore, the pressure against the dam is $60 \times 200 \times 62.5 = 750{,}000$ lb. Ans.

29. Dams to divert the course of water are subjected to little or no pressure and may therefore be an ordinary wood, brick, or stone stopping with water-tight joints. A dam of this nature may be constructed of two walls of plank supported by props firmly fixed in the top and bottom and with the space between filled with puddled clay, or, better, with concrete. The joints of the planks should be battened on the side next the water. Fig. 13 shows a plan (*a*) and section (*b*) of such a dam, in which *a* are posts; *b*, planking; *c*, battens; and *d*, the puddled clay, which is from 1 to 2 feet thick. The small pipe near the top permits the air to escape while the water is rising. The large pipe at the bottom is for draining off the water.

30. Wedge-Shaped Wooden Dam.—Fig. 14 shows a **wedge-shaped dam** that may be applied in most cases where no other dam can be effectively placed. This dam consists of sections of wood, carefully dressed with a taper, and placed with the thick end next the water. The taper of each piece depends on the radius of the curvature of the dam and is greater for a dam with a small radius than for one with a large radius. Each timber should be properly numbered, so that when the separate pieces are taken into the mine they can be placed in their proper positions. Thoroughly dried timber should be used, as that will swell when wet and tighten the joints. The lengths of the tapered pieces, or the thickness of the dam, will depend on the pressure that the dam is to resist and may vary from 3 to 8 feet. Notwithstanding the most careful wedging, the pressure on the face of such dams is sometimes great enough to move the whole

structure; therefore, it is advisable to dress the sides of the passage in such manner that the pressure will tend to wedge the structure tighter.

While the dam is being constructed, it is necessary to insert iron pipes about a foot from the bottom, of sufficient size to carry off the water that would otherwise accumulate and prevent the completion of the work. In Fig. 14, *a* is a drain pipe; *b* is a manhole which is about 18 inches in diameter and 2 feet from the bottom, and permits the ingress and egress of the workmen during the construction and wedging of the dam. A pipe *c*, from 3 to 6 inches in diameter, placed near the top, and provided with a valve, allows the air to escape while the water is rising. If at any time it is desired to draw the water off slowly, this valve can be opened.

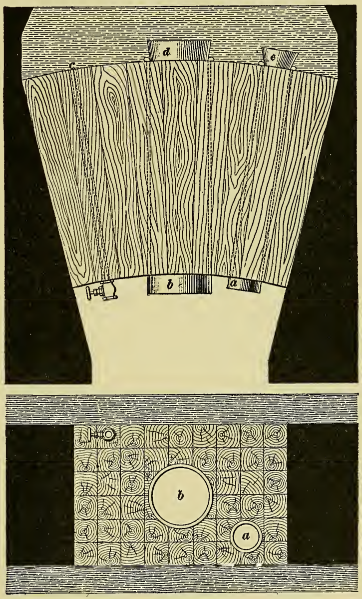


Fig. 14

The sides of the excavation for the dam should be lined with tarred flannel, so as to form a water-tight joint with the timbers. The tapered timbers are next placed in proper position, and dry wooden wedges, 12 inches long and 3 inches by 1 inch at their heads, are driven between the joints. Smaller wedges are driven around the pipes, as long as they can be entered, after which a chisel is used to prepare places

for their insertion. When the wedging is finished, the workmen drive the plug *e* into the pipe *a* through which the water has been flowing. They then pass through the pipe *b*, drawing into place the plug *d*, which has been placed convenient for so doing, and by this means stop up the manhole. It is stated that dams of this description, constructed of first-class wood free from defects, will resist a pressure of 260 pounds per square inch. Other designs for wooden dams have proved effective, but all depend on good workmanship in construction, as well as on design.

31. Flat Wooden Dams.—Fig. 15 shows the plan of a

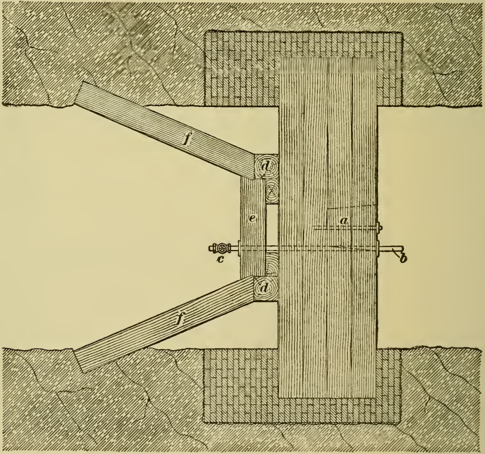


FIG.

wooden dam erected in a colliery to hold back water when the mine was flooded to extinguish a fire. The tunnel was 10 feet by 7 feet, in section, and notches 3 feet deep were cut in each rib and in the bottom. About each end of the timbers forming the dam, brick were laid in cement. The inside timbers were yellow pine while the two back timbers

were oak. When placing the first two rows of timbers, a manhole *a* made in keystone shape was used, but this was blocked up and bolted before the oak timbers were placed. The drain pipe *b* extended through the four timbers and was supplied with a cock *c* and a pressure gauge. This structure was reenforced by the posts *d*, the tie *e*, and the braces *f* fitted together as shown. These timbers were placed one on top of the other from the floor to the roof, and the braces *f* fitted and wedged into notches in the sides of the tunnel.

32. Brick Dams.—The **brick dam** shown in plan in Fig. 16 has a maximum radius of 30 feet and a thickness of 15 feet from *a* to *b*. These dams are constructed to wooden templets, termed *centers*, which are placed in position before the brickwork is commenced, and by the use of these centers, the exact radius and the proper curvature can be followed by the masons better than by the use of the long sweeps that would otherwise be required for determining the curvature of the wall. The arches marked by the arcs *c d*, *e f*, and *g h* are skewed into hitches cut in the walls so as to form skew-backs, thereby increasing the strength of the arch as the pressure is increased. These hitches receive the pressure in such manner as to produce an inward thrust and thus reduce the liability of breaking out the walls. The radius of curvature for masonry dams depends on the pressure to be

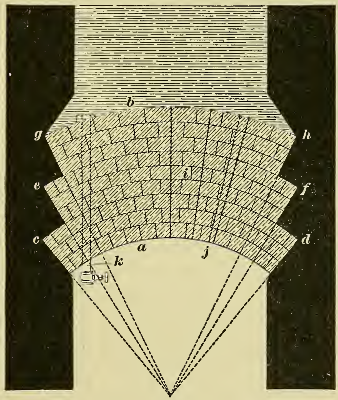


FIG. 16

resisted and the size of the opening. The dam is provided with a manhole *i*, an air vent *j*, and a pipe *k* for draining off the water.

33. Fig. 17 shows a plan of a dam built of two spherical brick arches *a*, *b* from 6 to 12 feet apart, the space between being filled with puddled clay, or, better, with concrete. This form of dam is suitable where the resisting walls are soft. Pipes are inserted in these dams, as in wooden dams, and for the same reasons.

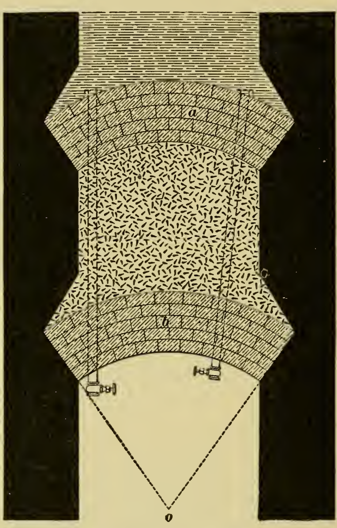


FIG. 17

34. Fig. 18 shows a plan (*a*) and vertical section (*b*) of a **horizontal brick dam** built at a colliery to shut off a large inflow of water from the roof close to the face of a chamber. As there was considerable depth of wash, or drift, over the seam, it was thought advisable to abandon, for a time, all mining at that level until the coal below was worked out. The dam was made 5 feet thick, of brick laid in cement, and its length from pillar to pillar was 25 feet, arching from bottom to top. In the figure, *a* is a cast-iron pipe for the escape of water while the dam is being constructed; *b*, a tapered white-pine plug turned to fit the pipe; *d*, a manhole used by the workmen as an escape after having finished the dam on the inside and having driven the plug *b*; *v* is the smaller air vent. The soft stratum

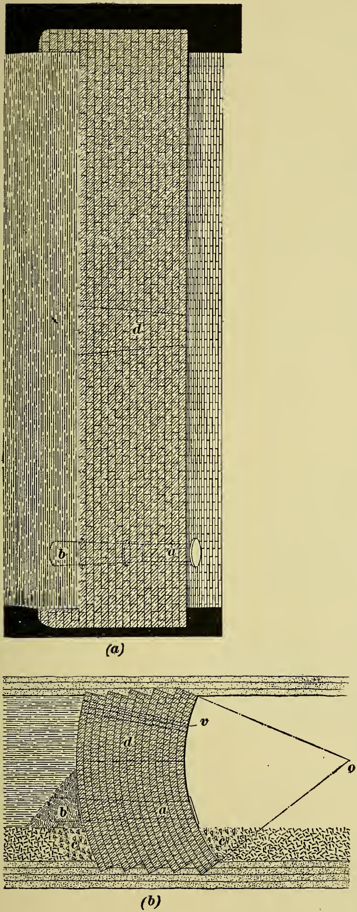


FIG. 18

immediately under the coal was cut away and the brickwork skewed into the harder stratum. This dam is formed of separate cylindrical arches, each of which is skewed into the top and bottom; and built across the passageway, because it would be more expensive to arch a wide dam longitudinally. Concrete *c* was placed at the front and back of the dam where the soft bottom has been taken up.

35. Stone Dams. Fig. 19 illustrates the plan (*a*) and cross-section (*b*) of a dam in the Curry Iron Mine, at Norway, Michigan, constructed to keep the water that came from some exploring drifts out of the mine workings. Originally, it was constructed of sandstone 10 feet thick and arched on the face with a radius of 6 feet. A piece of 20-inch pipe *a* held in

place by three sets of clamps and bolts *b* passing through the stonework provided a manhole through the masonry. A 5-inch drain pipe *c* was also carried through the dam and secured by clamps. When the pressure came on it, the dam was found to leak, so the water was drained off and a 22-inch brick wall built 2 feet 4 inches back of the dam, the space between being filled with concrete; the manway and drain pipe were extended through the concrete and brick wall. Before closing the drain pipe, stable refuse was spread against the face of the brick wall and covered over with planks to hold it in place. After the manway and drain pipe were closed and the pressure came on the dam, it was again found to leak a little, but this soon practically ceased, showing that the stable refuse had closed the leaks. A pressure gauge in the head of the manhole *a* registered 211 pounds pressure per square inch, which corresponds to a head of water of 486 feet. The total pressure against the dam was over 800 tons, which it successfully resisted.

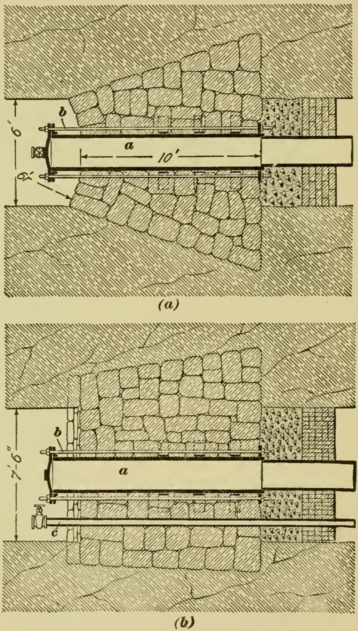


Fig. 19

36. Shaft Dams.—Abandoned shafts that pass through water-bearing strata or permit surface water to flow into a

mine, may be closed by an arch of masonry, as shown in sectional elevation in Fig. 20. The centers *a* in this particular case are made heavy and permitted to remain in place, since the dam can be examined from the stringers *b* on which they rest. Above the centers, the brick arch *c* is shown firmly skewed to the sides of the shaft. While the masonry is sufficiently strong to resist the pressure that will come on it, it may leak; and since water under heavy pressure will cut away metal, it is always better to puddle such structures with clay *d* tightly rammed down in order to assure water-tight work. To prevent the clay being disturbed by anything that may fall down the shaft, it is covered by stone *e* laid in courses as shown. This stone is further intended to prevent the clay being washed away in case any movement takes place in the shaft strata which might crack the brick work. During

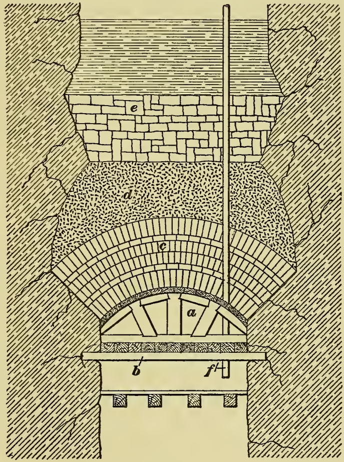


Fig. 20

the construction of the dam, the pipe *f* drains off the water that is caught in a temporarily constructed lodgment above the work, and it will afterwards answer for draining off the water in the shaft if for any reason it becomes necessary to remove the dam or make repairs.

37. Thickness of Mine Dams.—The cost of the materials used in constructing a mine dam is small compared with the importance of the work, so that it is not necessary to consider the thickness of the dam as affecting the amount

of materials used in its construction. The essential qualification is that the dam shall be amply strong, and for this reason it is usually built very much stronger than theoretical calculations may call for, and when formulas are used for calculating the thickness a large factor of safety should be used in the calculation. Several writers have given formulas for calculating the thickness of a dam, but the following, given by Combes, seem to be the most satisfactory.

1. For *straight dams*, where the ends of the dam are laid in a straight hitch in the ribs and no attention is given to the end thrust against the ribs, the thickness of the dam may be calculated by the ordinary formulas for a beam supported at both ends and uniformly loaded.

2. For *cylindrical dams*, the formula derived from that given by Combes is

$$T = .868 \frac{rh}{p} \qquad (1)$$

in which T = thickness of dam, in feet;
r = shorter radius of dam, in feet;
h = head of water, in feet;
p = allowable compressive strength per square inch of material used in building dam.

EXAMPLE 1.—What should be the thickness of a concrete cylindrical dam, with a shorter radius of 10 feet, to withstand a pressure due to a head of 100 feet of water, assuming the allowable compressive strength of the concrete to be 100 pounds per square inch?

SOLUTION.—Substituting in formula **1** the values given in the example,

$$T = .868 \times \frac{10 \times 100}{100} = 8.68 \text{ ft. Ans.}$$

3. For a *spherical dam*, the formula given by Combes is

$$T = r\sqrt{\frac{10p}{10p - 4.34h}} - r \qquad (2)$$

in which T = thickness of dam, in feet;
r = shorter radius of dam, in feet;
h = head of water, in feet;
p = allowable compressive strength per square inch of material used in building dam.

EXAMPLE 2.—What should be the thickness of a concrete spherical dam, with a shorter radius of 10 feet, to withstand a pressure due to

a head of 100 feet of water, assuming the allowable compressive strength of the concrete to be 100 pounds per square inch?

Solution.—Substituting the values given in the example in formula **2**,

$$T = 10\sqrt{\frac{10 \times 100}{10 \times 100 - 4.34 \times 100}} - 10 = 13.29 - 10 = 3.29 \text{ ft. Ans.}$$

SIPHONS

38. In many cases, water collects at some point in a mine lower than the main drainage ditches but higher than the level of the water in the sump, or some place where it may be dammed back from the workings. As it is not always desirable or expedient to cut a ditch deep enough to drain off this water, a **siphon** may often be used to carry it over the high point.

The principle on which the siphon works is illustrated in Fig. 21. A bent tube *c* filled with water is inserted into a vessel *a* containing water, the atmospheric pressure and the difference in the heights of the columns of water *ec* and *cd* will force the water in *a* to flow through the tube into the vessel *b*. The water will continue to flow through the tube as long as the water in *b* is below the level of the water in *a*, and the end of the tube is submerged in the water in *a*.

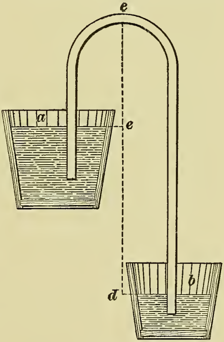


Fig. 21

The atmospheric pressure on the surfaces *a* and *b* tends to force the water up the tubes *ac* and *bc*; but when the siphon is filled with water, this tendency is opposed by the pressure of the water in each leg of the siphon. The atmospheric pressure on the longer leg *bc* is therefore opposed by a greater force than the atmospheric pressure on the shorter leg *ac* and as a result the water will flow from *a* to *b*. As the shorter leg is kept full by atmospheric pressure, the height to which the water may be raised at sea level is,

theoretically, about 34 feet, but practically it seldom exceeds about 28 feet.

39. Fig. 22 shows a siphon working in a mine where it is desired to convey the water from *D* to *E*, the level of the water in *E* being always lower than in *D*. The siphon consists of ordinary iron pipe fitted with three valves *A*, *B*, and *C*. On the suction end of the pipe, there is a perforated boot that keeps out chips and dirt, which might clog the pipe and prevent the siphon from working. In order to start the siphon, it is necessary to fill the pipe, which is done by closing the valves *A* and *B*, opening the valve *C*, and pouring water into the funnel *F*; the air is thus driven out from the pipes

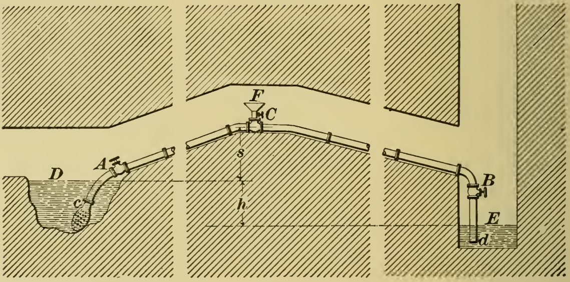


FIG. 22

through the funnel. When no more water can be poured in without overflowing at *F*, the valve *C* is closed, and the valves *A* and *B* are opened, when the water in the siphon will commence to flow.

40. Fig. 23 shows a very convenient method of filling the pipe with water when the siphon is used to carry the water from a local sump *M* to the main sump *E*. *s* is the height of suction; *h*, the head that induces the flow; *A*, the valve at the suction end; *B*, the valve at the delivery end; *H*, the column pipe of the main pump; *C*, a small pipe leading from the column pipe to the siphon, communication being opened or closed by aid of the valve *D*; *K*, a chamber

into which the air escapes when the pipe is being filled; and *L*, a valve that controls the communication between the siphon and the air chamber. In order to keep the air from getting past the valve *L* when it is closed and destroying the action of the siphon, the chamber *K* is kept filled with water. A rod *G* fastened to the short arm of the lever *F* has attached to it the handles of the valves *B* and *D*, and the weight *I*. When in the position shown, the valve *B* is open and *D* is closed. In order to start the siphon, the valve *A* is closed and *L* is opened. The lever *F* is then pulled down; this action raises the handles of the valves *D* and *B* to the position shown

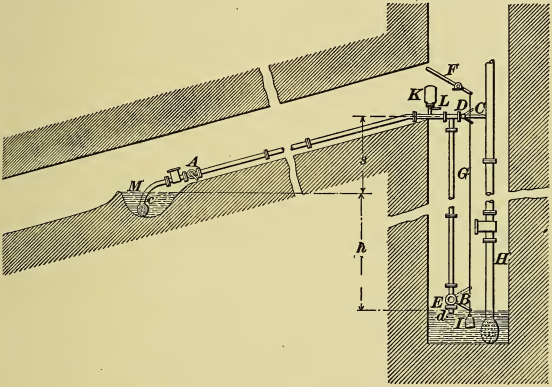


FIG. 23

by the dotted lines, opening the valve *D* and closing the valve *B*. The water flows into the siphon from the column pipe through the small pipe *C*. When the siphon is filled and the water appears at chamber *K*, the valve *L* is closed and the lever *F* is released, the weight *I* pulling it into the position shown, thus closing the valve *D* and opening the valve *B*. The valve *A* is then opened and the siphon is in working condition.

41. Air in a Siphon.—In order that a siphon shall work properly, it is necessary to provide means for the

escape of air, which will enter the pipe in spite of all precautions, and, when once in, will collect at the highest point of the siphon because the pressure there is least. Even

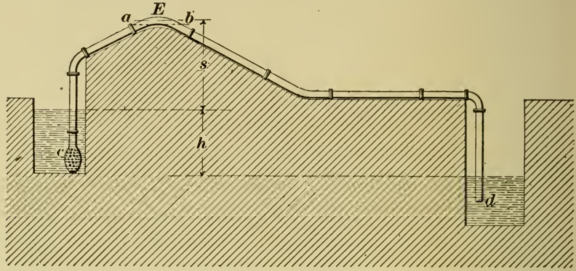


Fig. 24

though the joints are perfectly air-tight, the water absorbs air, which is given out again as the pressure lessens. Then, too, the pipe seldom runs full continuously, and air enters it unless both ends are submerged in water. Since the air

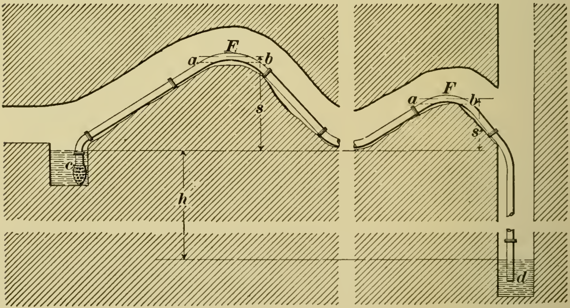


Fig. 25

always seeks the highest point of a siphon, sharp bends at this point, as at E, Fig. 24, should in all cases be avoided; a long bend, or a straight level pipe at the highest part, is most satisfactory.

42. A siphon with a sharp bend, as in Fig. 24, will not work well, as the air seeks the highest point E, and is compressed to an amount represented by the difference in pressures of a column of water whose height is s, in feet, and one 34 feet (the height of a column of water that the atmosphere will support). Suppose that, in the figure, $s = 22$ feet; then the pressure of the air at E will be $34 - 22 = 12$ feet of water $= 12 \times .434 = 5.208$ pounds per square inch. This pressure will not be materially increased by the addition of a little more air. When the volume becomes sufficient to occupy the space aEb, the dotted line ab representing a horizontal line just touching the bottom of the inside of the pipe, the water cannot get through the bend and the siphon is useless. This is true also of a siphon with a double bend, Fig. 25. Here the air collects at E and F. This is a very bad construction and should in all cases be avoided.

43. A device that will remedy the bad action of a siphon to a considerable extent, by permitting the air to escape, is

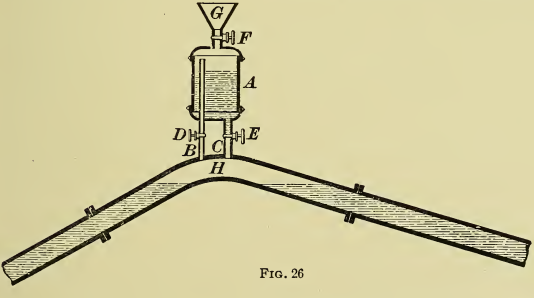


FIG. 26

shown in Fig. 26. A is an air-tight vessel connected with the siphon by pipes B and C provided with valves D and E. The pipe B extends to very nearly the top of A, while the pipe C just enters the bottom. On the top of the vessel, there is a funnel G and a valve F. When the air has collected in the siphon and stopped the flow, the valves D and E are closed and the valve F opened. Water is then poured into A

until it is filled and overflows the funnel G. The valve F is then closed and valves D and E opened. Water will flow through C and the air will ascend through B, until the air is all out of the pipe. This being done, D and E are shut and F opened. The vessel A is then filled with water, F is shut, and D and E are opened and left open. Any air that enters the siphon will, instead of collecting at H, seek the highest point by ascending through B, forcing a certain amount of water through C into H. This will continue until A is filled with air, when the valves D and E should be shut and the vessel A refilled, as before described. This arrangement may also be used to fill the siphon for the purpose of setting it to work.

44. Discharge of a Siphon.—Theoretically it makes no difference whether the discharge end of a siphon is submerged or not, but practically it does, for the reason that, if the siphon is not flowing full, the air will enter and work its way to the highest point. It is rather an advantage to have the suction end of the siphon larger than the long leg, since the resistance encountered by the water on entering is thereby lessened. A siphon will work better when using cold water than when using warm water, since water vapor collects and opposes the action of the atmosphere; hence, it works better in the winter than in the summer.

The amount of water that a siphon will discharge is calculated by the formulas given in *Hydromechanics* for the discharge of a pipe. The formulas for the flow of water through a rough pipe are taken as conforming more nearly to the ordinary mining conditions than would those for smooth pipes. These formulas assume that the pipe is running full of water and without any air in it. These conditions seldom hold in a mine siphon, so that the theoretical flow of water is not often obtained. The head is, in all cases, the distance marked h in Figs. 22 to 25, and the length is the whole length of the siphon from the suction end to the discharge end. In finding the head h, it is assumed that the discharge end is submerged; then the head is the vertical distance, in feet, between the level of the water

at suction and the level of the water at discharge. If the discharge end is not submerged, the head will be the vertical distance between the level of the water at the suction and the end of the discharge pipe. It makes no difference, in measuring the head, how far below the water the ends of the siphon may extend; the two ends of the siphon may, in fact, be level. The head is measured as described and the direction of the flow will always be from the higher to the lower water level.

EXAMPLE.—A siphon has a total length of 1,420 feet of smooth pipe, its diameter is 4 inches, and the distance between the water levels is 38 feet; what is the discharge, in gallons per hour?

SOLUTION.—The formulas for the flow of water through pipes as given in *Hydromechanics* may be used for calculating the flow through a siphon; the approximate formulas given for rough pipes will be sufficiently accurate for most calculations in mining practice, but where greater accuracy is required the fundamental formulas may be used. The formula for the flow of water through a rough pipe is

$$Q = .89\sqrt{D^5 h}$$

in which Q = cubic feet of water discharged per second;
D = diameter of pipe, in feet;
h = fall per thousand feet of length.

Substituting the values given in the example,

$$D = \frac{1}{3}\text{ ft.}, D^5 = \frac{1}{243}; h = \frac{1{,}000\,H}{L} = \frac{1{,}000 \times 38}{1{,}420}$$

then

$$Q = .89\sqrt{\frac{1{,}000 \times 38}{243 \times 1{,}420}} = .29535 \text{ cu. ft. per sec.}; .29535 \times 60 \times 60 \times 7.48$$
$= 7{,}953$ gal. per hr. Ans.

WATER HOISTING

45. Bucket Drainage.—It is customary, when sinking shafts or working mines in which there is little water, to hoist it in the regular rock or ore buckets. When a somewhat larger quantity is encountered, but still not enough to warrant the installation of an expensive pumping plant, a sump large enough to hold all the water that will accumulate in 24 hours is excavated at the bottom of the shaft and the water hoisted in special buckets, similar to that shown in Fig. 27. Buckets, or rather tanks, are often used in cases of emergency to assist

the regular pumping plant in keeping water out of mines in wet times, when the inflow is so great as to threaten to flood the mine and drown the pumps; they have also proved efficient in unwatering mines that have been flooded and in which the pumps have been covered with water.

Various plans are adopted to use water tanks instead of pumps; for instance, tanks may be attached beneath the hoisting cages, or water buckets may be hoisted on the cages alternately with the coal or ore. All plans, however, that require water to be hoisted in the same shaft compartment as the mineral have proved objectionable.

46. Objections to Bucket Drainage.—Where buckets are used in shafts, larger sumps are required than are needed for pumps, particularly if water hoisting must be carried on at periods that will not interfere with active mining and hoisting, such as between shifts and at night. Another objection to using the main shaft as the water shaft is the alternate drying and wetting of the timbers, which will cause them to decay more rapidly than if kept dry or wet. Again, in cold weather, ice is likely to accumulate in downcast shafts, and if men enter and leave the mine under such conditions they will be subjected to dangers that should be avoided. The filling of the buckets and their discharge at the surface are sources of annoyance where the shaft must be used for other purposes, unless special arrangements are made, and these, possibly, will interfere with others of more importance. The objectionable features, however, apply only when a shaft must be used for other purposes than hoisting water. Whenever a shaft is sunk purposely for hoisting water, the first cost is objectionable, but the advantages to be derived from the shaft must be considered in connection with the cost.

47. Advantages of Bucket Drainage.—Aside from the cost of the equipment, the simplicity of construction and the location of all the operating machinery at the surface, where it may be inspected and repaired in daylight, are of great advantage in hoisting water from mines. The machinery, also, is less complicated and requires fewer

repairs than pumps, besides being less troublesome to install. Another advantage is the avoidance of underground steam lines with their large condensation losses, besides the attendant evils, such as heating the mine air, thus causing mine timbers to dry rot and men to suffer when at work, both from heat and from the interference with the ventilation. Damage to roof and the danger from fire incident to the use of steam pipes is avoided, while the troublesome problem of exhaust steam does not exist. Pumps must be housed in excavations that are strengthened in the best manner, regardless of expense, in order that roof falls and squeezes may not occur and injure them. All this expensive work is unnecessary when buckets are used for mine drainage. Steam pumps, when submerged, will not work to advantage, if at all, while a plant using bucket drainage can never be submerged.

WATER BUCKETS AND TANKS

48. Water-Bucket Valves.—The water-hoisting bucket shown in Fig. 27 is designed for use in mines where only a small quantity of water accumulates. The valve *a* is raised by the bucket striking the water, but is prevented from raising too high by the stop *b*. As the bucket is hoisted, the valve seats and holds the water until the bucket is discharged. If there is no valve in the bottom, one lip of the bucket must be weighted so that it will dip. This method of filling buckets is objectionable, since they must turn over on the side and allow the bail and slack rope to assist in dipping them; then when they are hoisted the slack comes up with a jerk on the bucket and causes it to rock and spill in its flight up the shaft. When dip buckets reach the surface, they must be tilted in order to

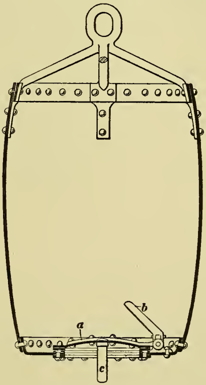
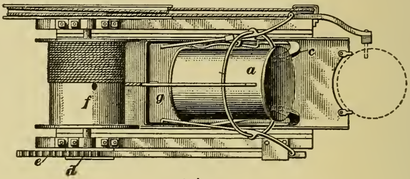


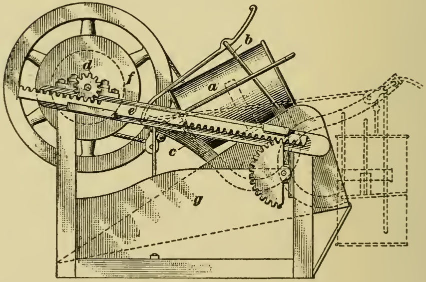
Fig. 27

discharge the water; valve buckets can be landed in troughs, the landing pushing up the valve stem *c* and with it the attached valves, thus permitting the water to flow out through the bottom.

49. Automatic Bucket Dumps.—One objection to tilting buckets is the slopping that occurs when they dis-



(a)



(b)

Fig. 28

charge their water; suitable arrangements, however, can be provided to overcome this feature. Fig. 28 (*a*) is a plan and Fig. 28 (*b*) an elevation of an apparatus that can be used for dumping water buckets. As the bucket *a* reaches the surface, it enters an iron basket frame *b* that is attached to two movable arms *c* connected to gear-wheels and an axle *d* by the rack bars *e*. The frame holds the bucket in a vertical position until it reaches a point over the trough *g* where there

is no danger of its contents going down the shaft. The gear-wheels working in the two inclined top, or rack, bars *e*, are fitted with teeth, or racks, so that they will move toward the hoisting drum *f* in order to spill the bucket into the trough *g* when coming up. After the bucket reaches the pivoted arms *c*, a continuation of winding raises these arms and in so doing causes the top bars *e* to move from over the shaft toward the drum. When the tilting bars have assumed the position shown, the contents of the bucket will have been discharged. The rope now being slackened on the drum, the top bars will move toward the shaft by gravity and in so doing move the gear-wheels and the tilting bars back to the position indicated by the dotted lines, from which position the bucket descends into the shaft. The basket *b* not only prevents the bucket tilting when over the shaft, but also prevents the edge of the bucket striking the trough.

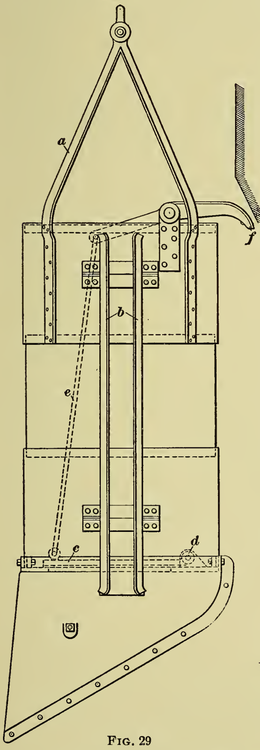


FIG. 29

50. Water Tanks.—Water buckets not exceeding 200 gallons in capacity and similar to those described are kept in stock by mine-supply houses; larger sizes, however, are considered tanks and must be constructed to order, for which reason a more detailed description is given. Mine water is often so corrosive that it is difficult to keep rectangular-shaped water tanks from leaking, even when

braced by angle iron at the corners, for which reason cylindrical tanks are frequently used.

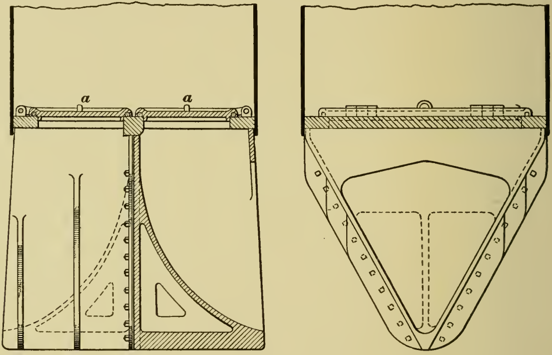
Fig. 29 shows an emergency tank used at the William Penn colliery in the anthracite regions of Pennsylvania. It is an automatic, bottom-filling and bottom-dumping tank having a capacity of 1,320 gallons. The shell is made of $\frac{3}{8}$-inch boiler plate and is double-riveted. Four bales *a* of $1'' \times 3''$ angle iron are placed equidistant around the upper circumference of the shell, to which they are riveted. The two guides *b*, one on each side of the tank, slide over the shaft guides and steady the tank during hoisting. The intake is a flap valve *c* hinged at *d* and connected, by a reach rod *e*, with a trip lever *f* that automatically opens the valve by contact with a projection in the head-frame. The bottom of the tank is provided with a **V**-shaped discharge casting, which strikes the water in the sump with less shock than it would if the bottom were flat. This wedge-shaped bottom, during the discharging period, also directs the water one side to a trough. The objections to this style of tank are: its unsteadiness when hoisting at a high speed; its slow discharge; and the side pressure created by the water entering the tank from one side only. The leverage produced by this lateral pressure when the tank strikes the water is so great that it damages the guides and requires their frequent renewal. The large valve is subjected to considerable shock from the rush of water, and, even though protected, is subject to damage. Flap valves of this description are not considered as satisfactory as double valves in water tanks of such large size where subjected to heavy blows.

51. End-Dump Tanks.—The tank shown in Fig. 29 has given place to that shown in Fig. 30 (*a*) and (*b*), which is an **end-dump tank,** 4 feet in diameter inside, made of $\frac{5}{8}$-inch boiler plate, and double-riveted. The length over all is 16 feet 6 inches, and its capacity is 1,440 gallons of water. To keep the tank steady in a vertical position, the shaft is provided with guides on three sides and the tank is provided with a shoe for each guide. The extra, or third, guide and

(a) (b)

FIG. 30

its corresponding shoe *a* are on the side toward which the tank dumps. This guide comes to an end at a point near the top of the shaft so that, when the dumping wheels *b* engage the dumping rails, the tank, which is pivoted near the bottom on the axle *c*, may swing and empty itself. The two valves *d* in this style of tank are termed **butterfly valves** from the angular positions they occupy when seated or opened. The lateral strain on the guides is not so great with a butterfly valve as with a single valve, but a further improvement is shown in Fig. 31 (*a*) and (*b*), where an open



(*a*) (*b*)

Fig. 31

casting having a central partition forms a perfect wedge, thus entirely avoiding the side thrust that would come on a slanting discharge bottom. It will be observed that the valves *a*, Fig. 31, swing outwards, instead of inwards, and seat in the center.

52. Hoisting Water on Slopes.—Water tanks are also sometimes used both in emergencies and permanently for unwatering slope mines. These tanks or cars are arranged to dump into water-tight chutes, and taken as a whole the system would be quite effective were it not for the objectionable features that are mentioned in the following articles.

53. Water-Tank Car Wheels.—Slope car wheels running in the same straight line soon become grooved, even under the most favorable circumstances; but when the car wheels are dipped in acid mine water, the wear is materially increased. The water dripping from the car also corrodes the rails; and if that water is very acid the rails in the sump are quickly destroyed. Unless special arrangements are made, the journals and journal boxes soon become corroded, necessitating repairs. These objections have been overcome, to a certain extent, by making the flanges on the wheels high, to keep them on the track, and by using self-oiling wheels with bronze bushings that fit closely over bronze collars on the axles, instead of ordinary car wheels and iron axles. These arrangements are effective so far as the corrosion of the journals is concerned, but the grooving of the wheels, and the expense of replacing wheels and soft bronze bearings, have not been overcome, particularly on slopes with slight inclination.

54. Speed of Hoisting Water on Slopes.—Owing to irregularities that occur in slope tracks and to other conditions, which may cause the slope car to leave the track, the speed of hoisting is always less on slopes than in shafts. If the car strikes the water at a high speed it will in all probability leave the track, while if it enters the water at only moderately high speed, a small chip on the track or some submerged object may cause it to be derailed.

55. Operation of Tanks.—To successfully operate tilting water tanks, a rest must be arranged in the sump on which the lower tank, which is filling, is supported while the upper tank is discharging. Should the filling tank sink too deep in the sump, it would turn the tank at the top upside down and possibly damage the sheave. Discharging the water causes a sudden reduction in the load, which makes the operation of discharging somewhat delicate in deep shafts. Unless the hoisting brake holds the drum firmly when a tank is emptied, the sudden release of weight may allow the weight of the rope in the other compartment to

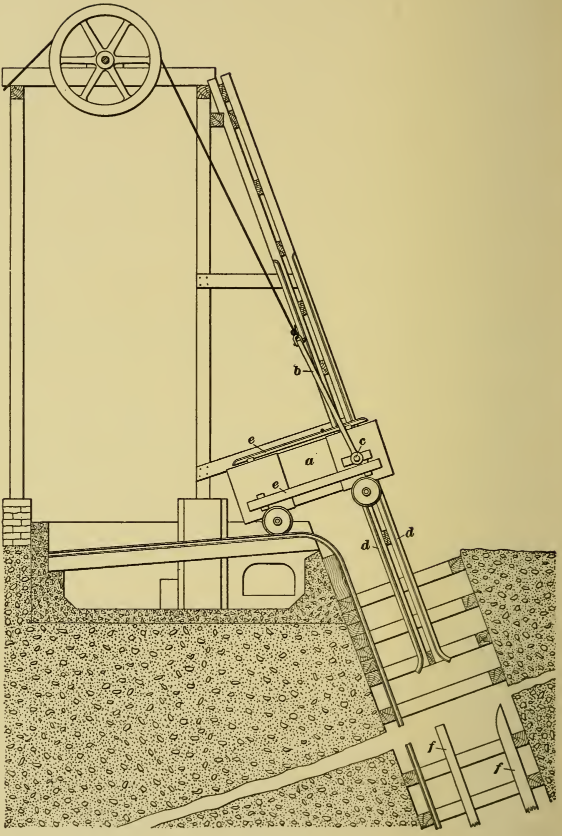


FIG. 32

move the drum enough to turn the tank upside down. These difficulties have been overcome in great part by the arrangement shown in Fig. 32, which was installed by the Union Coal Company at Shamokin, Pennsylvania. Fig. 32 shows the surface arrangements at this plant and the guides for keeping the car on the track as it enters the sump. The large iron tank car *a*, holding 1,400 gallons of water, is provided with a bail *b* that is pivoted on the axle *c*, which extends from side to side through the car and engages with plate guides *d* in the head-frame. The tank is also fitted on the sides and top with guide shoes *e* to engage the guides *f* at the bottom of the slope. The guides *f* extend 20 feet above the maximum water-line and hold the car on the track when it strikes the water. There is then no danger of floating substances derailing the car at the surface of the water; and since the slope has 70° pitch, there is no danger of submerged obstructions remaining on the track. The guides are thoroughly braced so as to take up any strains that may be put on them when the car strikes the water. This is a double hoist, one car ascending while the other is descending; consequently, to prevent the upper car being raised too high at the landing, a timber rest is provided in the sump for the lower car.

56. The Gilberton Water Shaft.—Water hoisting, in cases of emergency, is quite generally practiced, but as a substitute for pumping, the system has probably been most fully developed in the anthracite mines of Pennsylvania. One of the most extensive drainage shafts is the Gilberton water shaft, which is 1,070 feet deep and is intended to drain two collieries connected by a cross-cut tunnel. It is used exclusively for water hoisting, lowering supplies, and taking miners into, and out of, the mine. There are four shaft compartments; two 7 feet square for the water tanks exclusively, and two 11 feet 3 inches long by 7 feet wide for the men and supplies; the latter compartments, however, may be quickly changed for hoisting water. The shaft outside, is 26 feet 8 inches by 22 feet; inside, it is 19 feet 6 inches by

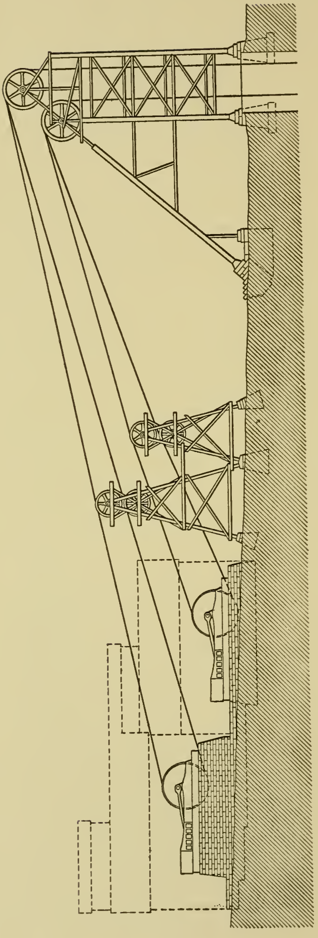


Fig. 33

14 feet 10 inches. The maximum drainage was calculated as 6,000,000 gallons daily during the wet season; and as most of this water would find its way into the lower levels when they are opened, it would require a very large pumping plant to handle the water. The question of building pumps and establishing central stations, to which all the water could be directed was thoroughly considered and weighed against the advantages that would be derived from sinking this shaft.

The machinery necessary to hoist water from this shaft is two pair of direct-acting horizontal engines, set as shown in Fig. 33, each with two steam cylinders 45 inches in diameter and 60 inches stroke. The hoisting drums are 14 feet 8 inches in diameter by 15 feet long, on each of which are two crucible-steel wire ropes 2 inches in diameter and 1,300 feet long. At fifty revolutions, or 500 feet

per minute, piston speed, the drum will hoist at the rate of 2,300 feet per minute. The drum makes 23.87 revolutions for each trip, hoisting from a depth of 1,100 feet. The ropes fasten in the center of the drum and wind toward the end, the fleet of the rope being 50.72 inches.

The water tanks for hoisting are of iron, 5 feet 6 inches in diameter and 14 feet long, making their capacity 2,400 gallons each. They are fastened to the rope by four chains of $1\frac{1}{4}$-inch iron, the chains being fastened equidistant on the circumference of the tanks. The valves in the bottom of the tank are arranged to open and close automatically, similar to that shown in Fig. 29, being opened by the guide shoes striking trips attached to the head-frame. The bottom of the tank has a side discharge similar to that described.

With the engines running at normal speed, two tanks of 2,400 gallons each should be hoisted per minute; this gives 120 tanks per hour or 2,800 tanks in 24 hours, amounting to 7,000,000 gallons per day, which is in excess of the estimated quantity by 1,000,000 gallons. By a slight increase in speed, 700,000 additional gallons of water could be raised daily, which, it is considered, will cover all emergencies; but if it should not, the other compartments can be depended on to supply the deficiency.

COST OF WATER-HOISTING PLANTS

57. The following costs of constructing and operating water-hoisting plants are given by Mr. R. V. Norris in a paper read before the American Institute of Mining Engineers. The cost of constructing two water hoists, including the cost of shaft sinking, head-frames, steam lines, and boiler plant at the Lytle and William Penn shafts of the Pennsylvania Railroad were as given in Table I. The cost of the shafts vary, one being more difficult to put down than the other. The steam lines are some distance away from the boilers in both cases, which accounts for their high cost.

The cost of operating the two water hoists given in Table I and another similar hoist operated by the same company is given in Tables II and III.

TABLE I

	William Penn Water Hoist	Lytle Water Hoist
Depth of shaft	953 ft.	1,500 ft.
Capacity of tanks	1,440 gal.	2,600 gal.
Size of engines	32 in. × 48 in.	36 in. × 60 in.
Size of drums	Straight 12 ft. diam.	Cone 10 to 16 ft. diam.
Capacity of hoist, 24 hours	2,100,000 gal.	3,750,000 gal.
Best record, 24 hours . .	2,291,040 gal.	3,772,600 gal.
Cost of sinking and timbering	$20,673.81	$22,641.63
Cost of head-frame . . .	4,224.13	3,540.58
Cost of water-hoist engines, foundations, and house	15,583.64	29,653.17
Cost of tanks and ropes .	2,393.23	3,899.65
Cost of steam line	3,726.12	4,951.17
Cost of boiler plant . . .		16,091.76
Total cost	$46,600.93	$80,777.96
Cost, excluding shaft sinking and steam plant . .	$22,201.00	$37,093.40
Cost per 1,000 gallons daily capacity, excluding shaft and steam plant	10.57	9.87

TABLE II

	Plant		
	Luke Fidler	Wm. Penn	Lytle
	Length of Time in Operation		
	3 Years	37 Days	1 Month
Depth of shaft, feet	960	953	1,500
Quantity hoisted, gallons	918,501,200	112,468,080	236,906,000
Average height hoisted, feet . .	960	727.8	740.6
Cost of labor, repairs, and supplies per 1,000 gallons	$.0114	$.0088	$.0071
Cost of steam per 1,000 gallons .	.0192	.0146	.0148
Total cost	$.0306	$.0234	$.0219

TABLE III

	Estimated Cost per 1,000 Gallons, 1,000 Feet Vertical Hoist		
	Luke Fidler	Wm. Penn	Lytle
Labor, supplies, and repairs for hoisting	$.012	$.009	$.008
Steam	.020	.020	.020
Total	$.032	$.029	$.028

HOISTING VERSUS PUMPING WATER

58. The average cost of pumping water at the Lykens Valley Coal Company is given by Mr. Norris at 5.33 cents, in 1901, and 3.9 cents, in 1902, per 1,000 gallons. The cost of pumping at the Lehigh Valley Coal Company's Hazleton shaft is said to be 1.25 cents per 1,000 gallons for 560 feet vertical lift; this is considered one of the highest-grade mine-pumping plants in Pennsylvania. In comparing the cost of water hoisting with the pumps at the Lykens Valley Coal Company, it will be noticed that there is considerable saving in favor of water hoisting; on the other hand, when comparing the cost of pumping at the Hazleton shaft with water hoisting, it will be found that the pump shows a considerable saving. This may be partly accounted for by the difference in shaft depths, the Hazleton shaft being 560 feet deep, while at the Lytle shaft water was hoisted 740.6 feet. This is not sufficient to account for the difference of .94 cent, in favor of pumping, and in comparison it should be considered that the steam cost of hoisting could also be reduced by the use of compound engines. When shafts are more than 500 feet deep, the advocates of water hoisting claim that it will probably be found more economical to use water hoists than steam pumps. Their claim is, however, not admitted by the advocates of pumping under similar circumstances.